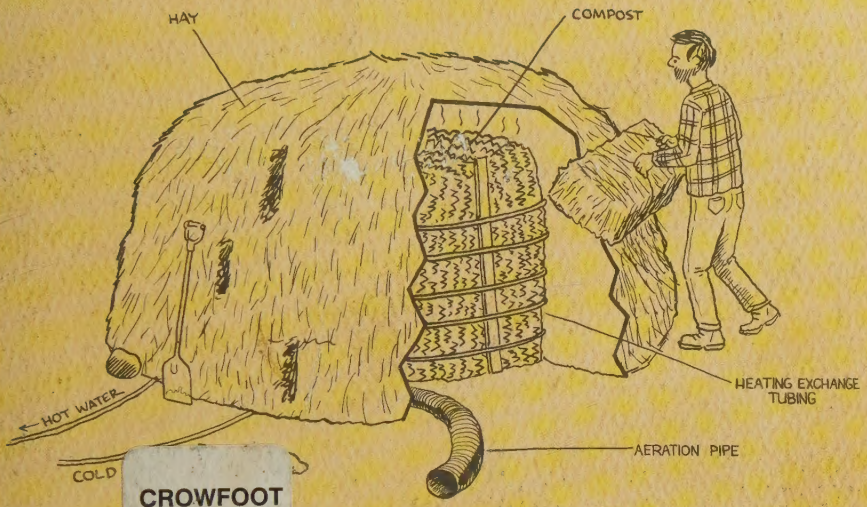
HOW TO HEAT YOUR GREENHOUSE, POOL, OR BUILDING WITH ONLY COMPOST!



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THE COMPOST-POWERED WATER HEATER

GAELAN BROWN

Of the humble things that might save this imperiled planet, compost is near the top of the list. When you read this guide, you'll understand why—and maybe you'll get off the pot and start working on it!" **—Bill McKibben**

"Of the humble things that might save this imperiled planet, compost is near the top of the list. When you read this guide, you'll understand why—and maybe you'll get off the pot and start working on it!"

—**Bill McKibben**, environmentalist, educator, bestselling author, and cofounder of 350.org

"Organic materials make up about two-thirds of the solid waste stream. Gaelan Brown's book will add momentum to the growing—and vital—movement to treat this waste as a valuable resource. As he demonstrates through a range of fascinating case histories, composting offers more than the most earth-friendly solution for feeding crops—it can also be a source of energy. *The Compost-Powered Water Heater* is rich with detail and includes clear instructions for those who want to create the innovative systems it profiles."

—**Carl Smith**, editor in chief, *Green Technology*

"It's not often you learn about a new approach to renewable energy that's easily accessible to homeowners. *The Compost-Powered Water Heater* is an indispensable handbook for anyone interested in diving into the details of how to do this for your own home or farm."

—**Kate Stephenson**, Yestermorrow Design Build School

"In addition to a fine how-to guide on constructing compost-heat recovery systems, Gaelan documents the many errors that inventors fell victim to in efforts to produce an efficient system capable of going the long distance of multiple heating seasons. Whether he is discussing the merits of a truly static system—complete with documentation by major universities—or the troubles of getting a stalled system operational again, this step-by-step manual makes you aware of all the potential pitfalls and how to avoid them. All said, this easy-to-understand guide is a must-read for serious compost-powered projects."

—**Paul Comey**, former Vice President of Environmental Innovation, Green Mountain Coffee Roasters

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"As industrial civilization begins its inevitable descent from the peak of fossil fuel production, technologies like compost-generated heat will be our lifeline to a decent and sustainable future. Gaelan Brown shows how these methods represent a holistic rethinking of the ways we inhabit the planet."

—**Ron Miller, PhD**, coauthor/editor
Most Likely to Secede

"After three decades in renewables, this took me by surprise—who would have thought you could heat your house or greenhouse with compost! Heating with compost is true ingenuity at work. It's ingenious."

—**Paul Gipe**, founder, WindWorks.org

"This book is practical, complete, useful, and well written. I learned a lot and am impressed with the innovation and the investment opportunity for compost power. It's an exciting opportunity that doesn't need government subsidies to be viable."

—**Doug Casey**, bestselling author of
Crisis Investing

"This book has given me inspiration to try out different techniques next time around, and I see where I made beginner's mistakes on my first mound. It is a very useful book that proves beyond doubt that there are endless possibilities for capturing and using the heat generated by composting organic material, both at home and on larger scales. We all know that the world needs cleaner energy sources and restored soils capable of supporting food production. With compost heat recovery you get both! And it doesn't have to cost a fortune. After reading this book you'll want to get out there and try building a compost mound for yourself."

—**Joshua Fenton Cabell**, Research Technician,
Bioforsk Organic Food and Farming Division,
Norway

"Gaelan Brown reveals one of the most exciting developments in renewable energy today, the ability to capture heat from compost and heat agricultural facilities to save money and extend growing seasons. This book is a must-read for those investing in a smarter future for themselves and others."

—**Simon Mainwaring**, author of *We First*

"A must-read for farmers and gardeners who want to reduce or eliminate their fuel bills."

—**Marshall Webb**, Forest Manager,
Shelburne Farms

"The future of our local and global societies will be based in biological systems capable of self-renewal if we are to live in a viable climate and vibrant communities. Compost heat will help power this future because of its utilization of local, organic materials and biological activity, resulting in genuinely renewable energy and valuable soil-building media. This book is an inspiring and meaningful step toward popularizing and advancing this promising technology."

—**Tom Gilbert**, former Executive Director,
Highfields Center for Composting

"It's so exciting to see this kind of innovation in waste management—a sector that government has monopolized for a very long time. It makes sense, then, that technologies have not kept up as they should. Gaelan Brown's project is a great example of creative ingenuity that can improve the world."

—**Jeffrey Tucker**, Liberty.me and
Ludwig Von Mises Institute

"This is the first definitive treatise on this important new aspect of organic materials recycling through composting. Brown has compiled a fascinating combination of clear technical details, entertaining profiles of pioneers in Compost Heat Recovery, and understandable practices to help anyone interested in heat recovery and reuse from composting."

—**Craig Coker**, founder of Coker Composting
and Consulting; contributing editor, *BioCycle*

"There has never been a better or more critical time to adapt and adopt radically different approaches to feeding and powering our planet. Gaelan Brown's informative and inspirational contribution accelerates the learning curve needed to bring a timeless yet underdeveloped form of energy and bio-logic into common practice."

—**Bruce Fulford**, President,
City Soil & Greenhouse LLC

"Farmers, gardeners, homesteaders, compost producers, florists, nursery owners, landscape contractors, sawmill operators, loggers, and garden supply retailers, welcome to Gaelan Brown's brilliant contribution to a more sustainable local economy. Starting perhaps with yours.

"*The Compost-Powered Water Heater* is a one-stop introduction to the history and science behind biomass composting and energy recovery, a compendium of lessons learned from backyard DIY experimenters and entrepreneurs running successful commercial operations. It is just plain fun reading about folks who are investing their time, resources, and creativity in an elegant, multilayered alternative to fossil fuels.

"So, should I place this book with my books on renewable energy, gardening, organic farming, local economics, resiliency, transition towns, permaculture, post-oil solutions or sustainability? Right now my copy resides on my bedside table. I read and reread it every night, letting it feed the dreams my wife and I share. We recently purchased a beautiful piece of land and are planning out the energy-efficient dream home that will give us safe haven in the second half of our lives. Since we both like to garden and base our diet on organic food, we've mapped out the location for gardens and a year-round greenhouse. Heating with compost might well become part of our plans.

"Where will Gaelan's book ultimately reside? Either next to the copier (I like to copy bits and pieces we want to incorporate into our plans) or nestled neatly between Eliot Coleman's *The Winter Harvest Handbook* and Paul Hawken's *Blessed Unrest: How the Largest Social Movement in History Is Restoring Grace, Justice, and Beauty to the World.*"

—**Dr. Richard Foley**, Professor, Sustainable Product Design and Innovation at Keene State College (NH)

"The only thing more surprising than the massive potential for compost-based heat capture is how long it's taken to get a book on the subject. This is a topic and book the world has needed for a long time."

—**Ben Falk**, M.A.L.D., Whole Systems Design, LLC

The Compost-Powered Water Heater

The Compost-Powered Water Heater

How to Heat Your Water, Greenhouse, or Building with Only Compost

Gaelan Brown

The Countryman Press
Woodstock, Vermont

Acknowledgments

Big thanks to the thousands of people who have encouraged me to bring compost power to life through my work and through writing this book. My gratitude to several dozen very active fellow tinkers whom I've been lucky enough to work with over the years on compost power projects, especially Brian Jerose, Karl Hammer, Bruce Fulford, Jason McCune Sanders, James McSweeney, Tom Gilbert, Josh Nelson, Kate Stephenson, Joe Oullette, Sam Gorton, Ben Falk, Gregor Barnum, Teresa Langston, Don Brumfield, Jaime Tibbits, and Kristen Hughes. And most of all I'm grateful for the support of my family, in particular my wife, Jasna, and my son, Aleks, who have inspired me while tolerating dump-truck loads of wood chips and compost power experiments taking over our front yard.

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Contents

Introduction 5

1 • A Brief History of Compost-Heat Recovery 7

2 • A Compost-Powered Present and Future 22

3 • The Science of Compost and Heat Recovery 29

4 • Large-Scale Isobar Systems 45

5 • Project Planning Guide for a Small-Scale Jean Pain System 67

6 • Project Planning Guide for a Large-Scale Modified Jean Pain System 84

7 • Greenhouse Application Design 94

8 • Understanding Feedstocks for Heat Optimization and Compost Quality 116

9 • Integrating with Other Systems 131

Afterword 144

Bibliography 148

Index 156

Introduction

This is the book that *I* wanted to write. Fortunately, Gaelan Brown caught the biothermal energy bug too, and you are about to be treated to the inspired results of his timely affair with the mighty microbe. *The Compost-Powered Water Heater* will surely help bring this underdeveloped energy source into common use.

My own preoccupation with biothermal energy began when I climbed over the fence that separated my grandparents' small Massachusetts dairy farm from the Waubeeka Springs golf course and stepped barefoot into a pile of scalding-hot grass clippings. That moment burned into my juvenile consciousness what I still think of as an almost magical attribute of the microbial world.

Innovators the world over have worked with composted materials for eons to recover heat for human use. Rudimentary and yet very effective technologies like French "hot beds," for example, garden beds heated with horse manure, have been around for ages because they are effective.

After the Three Mile Island incident in 1979, many of us turned our attention to developing alternatives to nuclear and fossil-fueled energy, experimenting with options like hydronic heating of water using copper and black poly pipes in a pile of poultry manure and sawdust. Of the myriad ideas, one held special promise. It was the work of French biothermal pioneer Jean Pain. It is on his revolutionary work that many of us have based our own enquiries, and it is Pain's model, along with new innovations such as the Isobar heat exchange method, that inform *The Compost-Powered Water Heater.*

In recent years biothermal systems have been constructed at public schools in Manhattan's Lower East Side; an urban farm at a women's shelter in Boston; at colleges and universities; on dairy farms and commercial composting sites in the US and Canada, and in many other settings in other parts of the world. Vermont, however, has become a biothermal hot-spot.

Here a unique blend of savvy farmers, seasoned composters, radical technologists, and creative northern-hardy growers have spawned a host of projects employing a variety of old and new approaches to capture and use compost heat and CO_2. Maybe it's the water, but I suspect it's just the right combination of long winters, abundant manure, and unreasonable optimism.

There has never been a better or more critical time to develop radically different approaches to feeding and powering our planet. That is why Gaelan's book fills me with optimism that we humans actually will embrace more carbon-conservative, locally reliant ways to feed and heat ourselves, that we will regenerate the soil that sustains us, and that we will clean the water that we borrow. Finally, there is a revolution breeding in the compost pile.

Bruce Fulford
President, City Soil & Greenhouse LLC

Chapter 1

A Brief History of Compost-Heat Recovery

Imagine being able to heat water, buildings, and greenhouses using energy captured from compost without buying or burning any fuel—while also creating a by-product that is worth more per ton than coal. If you'd like to stop imagining and hear about people who are actually doing this today—as you learn how you, too, can put compost power to work—keep reading.

Steaming compost at City Soil Boston
BRUCE FULFORD

Compost-powered, combustion-free energy is beyond just a fantastic imaginative possibility. Modern innovations around an old idea have made compost power a reality that many people are putting to work around the world. This book will give you everything you need to know to take the first steps toward applying compost power to your heating and hot-water needs, whether you are a homesteader, a landlord, a farmer, a commercial compost producer, or anyone else who needs heat and is interested in producing compost at any scale.

In the following pages you'll get a broad and deep introduction to compost-heat recovery at all scales. You'll learn about modern engineered approaches of extracting heat from compost systems using animal manure and food scraps as the main input, as well as time-tested low-tech methods that you can build in one day in your own backyard out of wood chips and sawdust.

You could think of compost power as hot shit, but there need be no obnoxious odors or manure involved. In fact, compost-heat-recovery systems

Ben Falk tests his improvised compost-heated hot tub in between his compost power mound and his greenhouse
BEN FALK

UVM students inspired by the compost power project at the Slade greenhouse
COMPOSTPOWER.ORG

often have the added benefit of reducing or eliminating odors that might otherwise be part of the compost-production process.

Since the dawn of agriculture farmers and foresters have understood that when biomass materials such as grass, food scraps, slaughterhouse waste, manure, or sawdust undergo the natural process of rotting, otherwise known as composting, heat is produced.

More than 2,000 years ago in northern China (and to this day in certain regions), peasant farmers commonly built raised "hot beds" filled with a 3-foot-deep layer of fresh manure underneath the topsoil, which produced enough heat to extend their growing seasons by a month or more in the autumn and in spring.

The same is true in northern Europe from the Middle Ages through the early part of the 20th century, with animal manure being used as a heat source under seedbeds. It was also common, particularly in eastern Europe and Iceland, for animal manure to be piled up against the outside walls of homes, providing winter heat and insulation. (Fulford, Compost Energy Center)

In cold climates many modern but older farmhouses have the original barn attached to the house, to share heat with the animals and their composting manure.

Maybe it was the cultural memory of enduring a constant odor of animal manure in the home that kept compost-heat recovery off the Western world's list of good ideas as we became more "civilized." It might be seen as ironic or sad that the advancement of Western civilization also resulted in

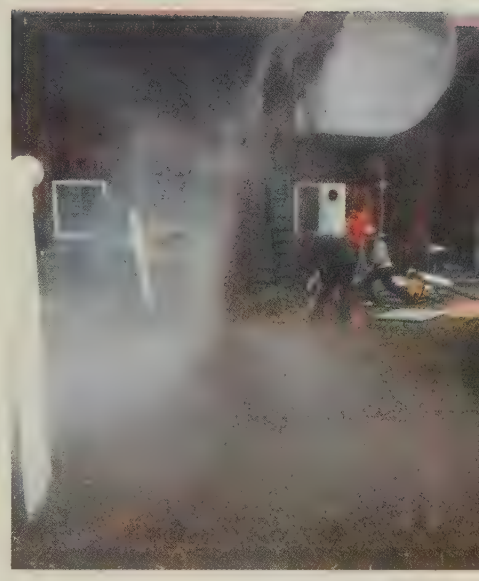
entire populations dumping most of their human and animal manure into rivers and groundwater, instead of composting it for heat recovery as had been done in the past.

In modern times, wet sawdust piles at lumber mills are almost always sending up steam even in the dead of winter. Barns filled with wet hay or corn silage have been known to catch fire due to spontaneous combustion from the composting process.

In short, rot makes hot. And at present there are people all over the world who seem to have collectively scratched their heads at the same time and said, "Let's use that compost heat. Why not?"

Hot shit is nothing new, but relatively few people have figured out ways to effectively capture this energy for productive purposes. Perhaps heating with compost hasn't been glamorous enough to have the broad appeal of an artisanal fireplace, a modern woodstove, or an engineered push-button combustion appliance.

Humankind's natural love of fire, and our cultural aversion to seeing shit and compost as elegant resources, may be changing. Our reemerging esteem for organic agriculture and sustainable energy has matured to a stage where the economic imperative of affordable



Steaming compost is dumped on the heat-exchange module at the Highfields compost power project. COMPOSTPOWER.ORG

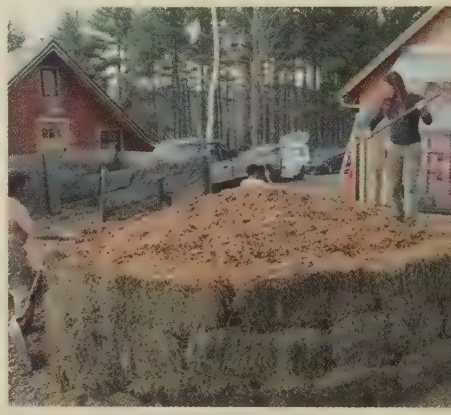
Jason McCune Sanders plumbs the manifold at the Highfields compost power project. COMPOSTPOWER.ORG

and localized energy is now driving exciting innovation in compost-powered energy.

This innovation means opportunity for many people to put this concept to work in their lives, in their businesses, and in their communities.

In recent years the resurgence of organic farming in Western economies has driven investments in expanded production of high-value compost. Cost increases for conventional fertilizers and shortages of supplies like potash have driven up the demand and prices for organic compost. Certified-organic fertility cannot use the chemically derived fertilizers of conventional agriculture that have been common during the past half century.

A truck dumps fresh compost feedstock and food scraps. HIGHFIELDS CENTER FOR COMPOSTING



Ben Falk's compost power mound during construction. BEN FALK

The corresponding investments in organic compost production have also sparked recent innovation on compost-heat recovery, particularly in the past decade in Vermont, Canada, and Germany, where several compost scientists, engineers, and tinkerers have, independently of one another at first, but eventually through collaboration, developed several economically viable methods of recovering predictable amounts of heat from the composting process.

Today there are many working examples of homes, greenhouses, and farms that have used compost-heat-recovery systems alongside existing heating/hot-water systems, reducing or eliminating the need for fuel combustion. These systems range from simple low-tech designs made mostly of wood chips and sawdust, to large-scale engineered systems at farms and compost-production facilities.

Galt's Gulch, Chile

In June 2013 a new "anarchist eco-village" outside Santiago, Chile, brought me down to build a compost-power system for one of its remote off-grid guesthouses.

This was one of the more picturesque projects that I have been involved with. A gravity-pressurized water line moves water through the system into the domestic water lines, giving guests a perpetual stream of hot water as needed without any fuel or power use.

This project consisted of 30 cubic yards of material and 600 feet of 1-inch poly tubing distributed across six layers within the mound. Straw bales were used as insulating/structural side walls, with one side of the mound built up against the exterior wall of the house.

All of the construction was done by three people working by hand over a two-day period with no tractor or other equipment involved. The material was delivered to the site in 50- to 75-pound sacks; we mixed everything together with rakes as we built the mound and added water.

We laid out 100 feet of perforated flexible drainage tubing on the ground before we spread out any feedstock material, to provide passive aeration to the microbes. One end of the perforated tubing terminated in the center; the other end extended to the outside air between two of the straw bales. We used straw bales to maintain the perimeter and provide structural side walls so that we could keep the hot mix inside the walls in a consistent column shape. A length

The finished compost-power project at an off-grid guesthouse at the "anarchist eco-village" of Galt's Gulch, Chile. COMPOSTPOWER.ORG

The first construction phase at Galt's Gulch. COMPOSTPOWER.ORG

ABOVE: *Ken Carpenter of Galt's Gulch hauls a bag of wood chips to the project site.* COMPOSTPOWER.ORG

RIGHT: *Aeration tubing and insulating straw bales at the site.* COMPOSTPOWER.ORG

of poly tubing that would eventually bring hot water to the house was laid in place ahead of time between the building and the location of the system.

The feedstock we used was 60 percent mill shavings of fresh pine, 30 percent sawdust, and 10 percent horse manure. We added a 24-inch layer of this on top of the perforated tubing, dumping, mixing, and spreading it around as we thoroughly soaked it with water.

Then we coiled the first layer of heat-exchange PEX tubing in concentric circles across the feedstock, spaced at 6 inches between each ring and 12 inches from the inner wall of straw bales; we got about 130 feet of tubing distributed. We spread a 10-inch layer of mixed feedstock on top of the PEX and soaked it with water. We repeated this process until we used up the material and the mound was about 6 feet tall. We laid out the second, third, and fourth layers of straw bales as we built up the mound.

Galt's Gulch Chile is planning to integrate compost production and compost-heat recovery into its overall business plan as part of the organic farm operations. The region is surrounded by farms, vineyards, and olive and citrus groves, with lots of market potential for organic compost in general. The community also sees compost-powered hot water as a great solution that members are hoping to incorporate into their own home design and construction plans.

Due to the dry climate of Chile, the system dried out about five months after construction, and the temperatures dropped to 80°F. Weekly maintenance of resoaking the mound with water resulted in temperatures coming back up to 110°F and higher.

Joe Oullette, inventor of the patented Isobar compost-heat-recovery system, inspects the aerted slab composting building at Sunset View Farm in New York.
AGRILAB TECHNOLOGIES

I have been involved with compost-powered heating systems in dozens of states across the United States as well as Quebec, Ontario, Siberia, Norway, Chile, Argentina, and many other locales. Of course many of the first attempts for various projects were not totally successful, but in recent years best practices have been fine-tuned to create a predictable and economically viable process.

Many of the small-scale experiments and modifications of the Jean Pain method of composting wood chips and capturing hot water have not performed as hoped, due to a number of variables explained in later chapters. However, many other projects have successfully generated large volumes of heat and hot water during winter months over long periods of time.

A more predictable and engineered approach to compost-heat recovery has also been developed by Agrilab Technologies and Joe Oullette of Acrolab Ltd. This approach pulls hot steamy air down through the compost into the floor and runs that air and vapor through a specialized heat exchanger. The Agrilab system is much more predictable, manageable, and reliable than the Jean Pain method, but requires more upfront investment, and is not yet suited for residential use.

The Agrilab system in general pays for itself in less than five years and is

ideal for commercial compost producers and farms with more than 100 cows or the equivalent amount of manure or other compost feedstocks such as food scraps and forest residues.

So how does compost heat really work? More detail is provided in later chapters. Briefly, however, any biomass material that has enough air and water present, and enough thermal mass, will naturally go through a thermophilic composting process, otherwise known as rotting.

The microbes that produce heat through the composting process need food, air, and water, like any other living organism. Even aside from our ability to use that energy, the heat has multiple benefits, such as eliminating pathogens to produce healthy soil.

Thankfully, the innovations made in recent years have proven that there need not be odors involved in the composting process. In fact, heat-recovery systems can reduce or eliminate odors from compost facilities.

One of the most significant pioneers of compost-energy systems in the recent past was researcher Jean Pain, who developed unique methods of compost production and energy capture at his organic farm in France in the 1970s. After years of research, this self-taught tinkerer unveiled methods of generating large amounts of 140°F water and natural gas by using shredded brushwood as his only input.

Jean Pain not only met all of his domestic hot-water and space-heating needs with compost, but also made enough natural gas to operate his farm equipment and vehicles, and generated all his own electricity from natural-gas-powered generators.

According to Jean Pain's documented results, he was able to capture more energy by composting and then digesting the woody material than he could have captured by simply burning all the wood. Many seemingly knowledgeable people, including college professors and engineers, have told me that this claim must be impossible—that there's only so much energy to be harnessed in a given mass of wood chips.

The Compost Power Network's experiments have at least partially validated Jean Pain's claim in this regard. More research is under way, but in a nutshell: Microbial respiration and digestion seem to be more energy-abundant processes than combustion. Microbes are more efficient at turning food into energy than is a woodstove. That should not be hard to believe, in my opinion.

It could be said that Jean Pain's innovations collected dust throughout most of the 1980s and '90s after he died in 1981. During this period a few research projects and educational programs were undertaken by the Jean Pain Institute, along with a handful of university research projects. There was a short list of pioneers who continued with compost-heat experiments based on what they learned from people like Dan Knapp, author of a chapter on compost heating of greenhouses in *The Solar Greenhouse Book* (Rodale Press), and Jean Pain.

Bruce Fulford of the Compost Energy Center and New Alchemy Institute (NAI), and Karl Hammer of Vermont Compost, are two of the most notable individuals who kept the concept of compost-heat recovery alive in the 1980s and '90s.

The NAI built a winterized compost-heated greenhouse on Cape Cod, Massachusetts, in 1984. The north wall of the greenhouse had a built-in compost chamber that provided heat to the soil, enabling winter vegetable production without other forms of space heating. Fans were used to pull air down through the compost and through a biofilter, pumping hot CO_2-rich air into the greenhouse.

In the 1990s Karl Hammer, founder and current owner of Vermont Compost, kept his greenhouses at a farm in upstate New York operating through the winter using the Jean Pain approach. But aside from a few university research projects and a few experimental projects by Bruce Fulford, the idea seemed to have been all but forgotten.

Compost Power "hackers" standing on top of a mound built at the author's house in 2009. COMPOSTPOWER.ORG

By the early 2000s a handful of additional innovators and tinkerers, operating independently of one another for the most part, developed promising approaches and started to revive Jean Pain's legacy. These individuals eventually formed networks of permaculture practitioners, engineers, renewable-energy experts, and compost scientists in Vermont through CompostPower.org, Highfields Center for Composting, Yestermorrow Design/Build School, and Agrilab Technologies.

In 2005–06 Agrilab Technologies installed its first compost-heat-recovery system using its patented Isobar technology, at Diamond Hill Custom Heifers in Sheldon, Vermont. The system generated more than 200,000 Btu/hr continuously, and the farm gained tens of thousands of dollars in compost sales annually. The system works by pulling air down into the floor of a compost-production area, actively aerating the compost; this eliminates the need for stirring and tumbling of the material. The hot air is then run through a patented heat exchanger, producing steady volumes of 120 to 130°F water. The first system was a success, but Agrilab had a slow first few years due uncertain performance and cost factors.

In 2009 the collaborations of several individuals in Vermont became more formalized through an open-source research project known as the Compost Power Network (CompostPower.org). This network has built or assisted with dozens of demonstration systems across New England and beyond, including successful experiments at a monastery in Siberia, a system integrated into a greenhouse at the University of Vermont (UVM), a system heating a college dorm at Evergreen State College in Washington State, and a project at an eco-village near Santiago, Chile. Many of these projects were used as training programs through workshops that I taught at Yestermorrow Design/Build School, UVM, Evergreen State College, and other venues.

In 2011 CompostPower.org published a *Design Guide* for do-it-yourselfers online while offering free advice and encouragement to people across the globe who wanted to do their own experiments.

During this same time frame, a German man named Heiner Cuhls began his own replications of the Jean Pain method. By 2011 he had started a company in Germany building dozens of small-scale Jean Pain–style systems and leading workshops across northern Europe. In 2013 Cuhls toured North America offering workshops and projects as well.

While many of the early compost power projects did not perform as expected, due to flaws in the materials or designs (using rot-resistant woods such as hemlock was a common mistake), in recent years several projects have produced 120 to 140°F water throughout Vermont's long winter, lasting up to 16 months before needing to be rebuilt. In many cases, after the heating cycle ends the compost is worth more than the material cost of the system in the first place, meaning that all the energy captured can be legitimately seen as free.

Ben Falk

The owner of the Whole Systems Design Research Farm in Moretown, Vermont, Ben Falk is one of Vermont's most innovative and prolific permaculture practitioners. He's part of a network of collaborators who eventually came together and formed the Compost Power Network.

In 2012 he built his first compost power system, with modifications suggested by myself and others from the Compost Power Network. He wanted to heat a new winterized greenhouse with the hot water. The greenhouse radiant heating system didn't get finished that winter, so he used his compost power system for a makeshift outdoor winter hot tub.

The video he shared on YouTube shows him demonstrating too-hot-to-touch water coming out of his system in midwinter, just after a heavy snowstorm in Vermont. It also includes a wonderful time-lapse series showing every step of the construction process, an excellent resource for do-it-yourselfers. Visit www.wholesystems-design.com for the video or find it on YouTube—you'll be glad you did.

Ben Falk of CompostPower.org and Whole Systems Design BEN FALK

Falk tests his compost power mound with an improvised winter hot tub. BEN FALK

Cecil Smith

Cecil Smith of Polar Solar. CECIL SMITH

The owner of Polar Solar, a solar hot-water installation company, Cecil Smith built a small-scale compost power system at his home in New Hampshire in 2010 after taking a Yestermorrow workshop that I taught.

Cecil's feedstock was 40 cubic yards of bark mulch. This was before anyone thought of putting flexible perforated tubing under the material. The mound itself was highly conical, with most of the 900 feet of heat-exchange tubing distributed in the lower half of the system. The conical shape meant that the upper levels of the mound were very narrow in terms of diameter, so there wasn't much room to embed heat-exchange coils in the hottest area of the system.

Cecil tied his compost power system into his solar hot-water system and into his radiator household heating system. For the first two months of winter the system performed beautifully, providing all the hot water they needed while also actually heating their house without the boiler running at all. He had to increase the circulation of 110 to 130°F water through his radiators more than usual, since radiators are designed for 180°F water. He documented capturing between 15,000 and 20,000 Btu/hr through November and December.

Smith's compost-power project, phase one.
COMPOSTPOWER.ORG

The project in progress (left) and completed (right). COMPOSTPOWER.ORG

By the end of December, however, he ran into problems. Once he turned on his thermostat-driven furnace, he struggled to make it interact properly with the preheated water from the compost. His furnace was tuned to produce 180°F water that was circulated through his radiators, returning to the furnace at temperatures of approximately 150°F. Because his furnace could not be adjusted to produce higher volumes of water in the range of temperatures produced by the compost, the water from the compost system was actually having a negative impact on his furnace.

At the same time, near mid- to late December the water temperature from his system took a nosedive to 80°F even though the temperature reading from the compost was still above 100°F. There was likely a flaw in the insulated below-grade pipe runs between the system and the house. But by mid-January the temperature in the mound had also dropped to 90°F. By April the mound temperatures were back up to 115°F, so Cecil continued to use his compost power mound for domestic hot water.

This particular project taught us many lessons, including the importance of aeration and well-done below-grade pipe insulation, and of understanding the adaptability of existing systems to make good use of 110 to 130°F water. There is also an open question in the minds of several people in the Compost Power Network about the viability of using bark mulch as a primary feedstock based on similar "winter stall" results from other systems. It seems that bark mulch may get overly compacted over time, especially if too much water is added to the material, blocking aeration.

Conan Eaton proudly shows off his hot box of shit. HIGHFIELDS CENTER FOR COMPOSTING

In 2012 Highfields Center for Composting, with support and collaboration from Bruce Fulford, Bill McKibben, Compost Power, Agrilab, and many other organizations, raised $40,000 in donations via a Kickstarter campaign to fund the next wave of research. At the same time UVM's Clean Energy Fund awarded $25,000 per year for three years of research and demonstrations on campus after Compost Power helped several enthusiastic students create a winning proposal. The first application of Compost Power at UVM was an attempt to heat the Slade greenhouse via a radiant floor heating system to keep it productive through the winter without fossil fuels.

By 2013 CompostPower.org had assisted with dozens of projects around the world, and Agrilab Technologies had reorganized with new leadership and an expanded team of people from the Compost Power Network. As of this writing Agrilab has designed and begun offering a containerized "plug 'n' play" version of its system, including lease-to-own financing.

This resurrection of Jean Pain's methods, along with the development of entirely new approaches like Agrilab's Isobar system, has created exciting new momentum. This momentum has also taken root across the globe with many people learning from the open-source experiments of others, finding ways to capture heat from compost.

It's an interesting coincidence that Agrilab Technologies and the tinkerers of Compost Power did their work independently in the early years, even though most of the people involved lived in Vermont; more recently the collaborations became much more active. Some say that innovation happens when an idea reaches its time, or when a common need sparks the same idea at the same time in different places. Many archaeologists believe, based on the evidence available, that the hatchet was invented at roughly the same time on several continents tens of thousands of years ago with no conscious communication among the so-called inventors.

As of this writing collaborative projects are under way among most of the previously mentioned people and organizations, including new market-ready systems being sold with bank-approved financing, and new research being undertaken. Compost power is now a market-ready and economically viable concept, and there is tremendous opportunity for innovative applications of it.

Chapter 2
A Compost-Powered Present and Future

Turning biomass "wastes" into pathogen-free compost that builds healthy organic soil is a simple and commonsense idea. Why take up space in landfills for food scraps that can be easily composted and used to improve soils and grow more food? Why spread raw manure on the fields when composted manure has better fertility, without the pathogens and runoff issues? Why burn wood chips for heat when we can get heat from those wood chips by composting them instead?

Usually the answer to these kinds of questions is, "Because we can." At the same time, we can also just do the math and realize that compost has *real economic value*: We can make or save money by composting. Raise your hand if you don't want to save money.

The fact that we can see the composting process as an energy source is part of a paradigm shift when it comes to the connections between ecology and economy. Long-term economic abundance is a result of ecological abundance.

What is permaculture if not humans figuring out ways to harness natural cycles that build regenerative abundance? Turning "waste" materials such as forestry residues, manure, and food scraps into high-value organic soil and base-load combustion-free renewable energy is about as regenerative as it gets.

The growth of organic agriculture is driving an ever-growing need for larger volumes of compost. Compost production will soon need to move beyond converting wastes into soil. The need for compost will make us look hard at rerouting our current manure and humanure waste treatment processes.

The economic viability of compost-powered energy must recognize the value of the compost after the decomposing material stops putting out heat. As I've previously mentioned, if the process is approached soundly, the value

Diamond Hill Custom Heifers' manure bedding is mixed and loaded onto the heat-recovery pad. AGRILAB TECHNOLOGIES

of the finished compost is higher than the cost of the initial feedstock and material-handling costs. Since the compost is worth more than the fuel, in essence all the energy captured can be seen as free.

Production of biomass materials such as forest residues, wood chips, et cetera, will eventually become at least partially driven by the compost producers' demand for materials, instead of compost producers relying on the waste streams of the timber industry and other biomass wastes.

At the same time, the values and uses of compost continue to grow and change. For example, some dairy farms in the Northeast are now using compost as their primary bedding material, instead of buying sawdust or other materials. Bedding needs to be fluffy, absorbent, and pathogen-free. Properly made compost is all of the above.

And it's not just commercial farmers who are investing in compost for their soil: We're seeing a continued resurgence of urban and backyard gardening and small-scale greenhouse operations around the world.

Forestry and farming often go hand in hand, particularly in terms of animal husbandry and compost. Most people think of food scraps and manure when they think of compost. But forestry is also an important aspect of the big picture. Compost-powered energy solutions based on forestry inputs can actually improve the health of our forests while providing new economic opportunity.

A farmer who keeps the upstream forest healthy protects the waterways and soil health that keep the farm abundant. The question of how to most effectively manage a forest, and how to integrate forestry with other farming practices, is an interesting topic for work outside the scope of this book.

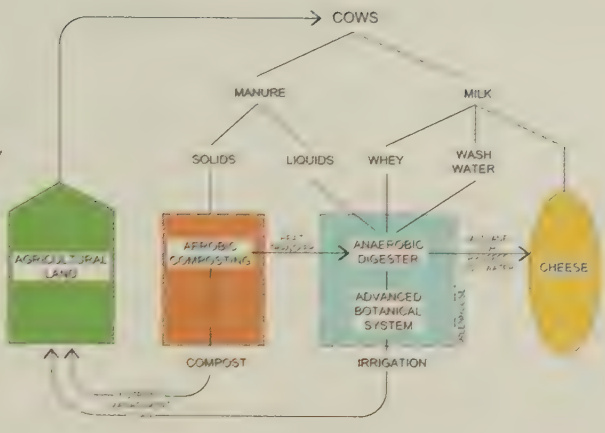
Jean Pain documented the sustainable forestry yields from his harvesting of brush and undergrowth. He was able to generate 40 cubic yards of wood chips from just 1 acre of forest, without cutting any of the mature trees. Every five years that same amount of material can be harvested again from brushwood that quickly grows back, all while the trees that are left standing are given some of that compost and more room to grow.

One of the driving forces for many farmers to get into compost production has been to offset the cost of their animal bedding. A 2,000-head dairy farm can spend more than $100,000 per year on sawdust for bedding. If the manure and bedding are composted, with just a portion of it sold, all of the bedding costs can be recovered. Or the compost produced could be used as bedding.

A concept complementary to compost-heat recovery that is gaining momentum in terms of on-farm manure management is biogas digestion. Digesters produce methane, aka natural gas or "Cow Power." The final product after a digestion cycle is complete is a large amount of clean-burning natural gas along with "cake"—an odorless, dry, soil-like material that makes excellent fertilizer. It also makes excellent bedding.

The cycle of bedding and manure being composted for heat recovery, and then digested for biogas production, also offers a promising approach, but very few farms are doing this. Jasper Hill Creamery, a 50-heifer dairy in Vermont that produces organic cheese, yogurt, and butter, is an interesting example. Jasper Hill recently installed an Isobar compost-heat-recovery system that provides hot water for washing, keeps the biogas digester warm, and heats a winterized greenhouse on the farm. Jasper Hill has one of the smallest-scale biogas digesters of any farm in the Northern Hemisphere, which is integrated into the compost-heat-recovery system.

Waterway pollution from runoff during rainstorms after farms spread raw manure on fields has very large negative impacts on the environment and human health. Raw manure is full of excess phosphorous that plants can't absorb, which sparks toxic algal blooms in rivers and lakes, along with other problems. Raw manure is also full of pathogens. Since converting this



Flow chart showing how the Agrilab Isobar compost-heat-recovery system is integrated with the biogas anerobic digester at Jasper Hill Farm.
JAMES COE,
JASPER HILL FARM

material into compost also produces net-positive energy, though, we have every economic and ecological reason to compost that shit first. Everyone wins. It's really that simple.

By simply composting their manure, farms can dramatically increase the fertility value of the material, improving crop yields, while dramatically reducing waterway pollution and earning a strong income from selling some of the compost. When the heat-recovery factor is added into this equation, the math can be very compelling.

Based on experiments of the Compost Power Network and others, a household-sized 40-cubic-yard Jean Pain–style compost system can produce more than 10,000 Btu/hr, or 3,000 watts (enough to heat the average home through a Vermont winter with a radiant floor heating system).

If Jean Pain's forestry yield scenario is similar in other regions—Vermont, for example—it means the average household needs access to just over 5 acres of forest for the sustainable brushwood harvest to supply all of their winter heating, without cutting down any of the mature trees in the forest, while making large amounts of high-value organic compost. Vermont has nearly 20 acres of forest per household.

Let's think about that for a moment. This means that it is possible for every Vermont home to be heated with wood, without burning anything, and without cutting down any of the mature trees, while building rich abundant soil.

Jean Pain

Jean Pain started composting shredded brushwood after being paid by the French government to thin the undergrowth in the forests of dry southern France to prevent wildfires from spreading. He had to figure out what to do with all the material and quickly realized he could make compost and soil with it. Over the years he recognized the potential to capture heat and spent more than a decade trying various approaches.

Ultimately he realized that if the wood chips were shredded to a very fine consistency the compost would aerate itself passively, without any stirring or turning of the material or any engineering required, with very high temperatures resulting. Since there was no wood chipper on the market that could produce material of the texture he thought would be best, he actually made his own wood shredder that could turn brushwood into a mulch consistency. To this day the Jean Pain Chipper is produced and sold in France.

His early attempts at heat recovery included running a stovepipe from a small building into the compost and back up into the building. This created a natural convection effect with a steady stream of warm air moving into the building. Eventually he figured out a way to coil water lines throughout the material and simply circulate water through the loops to generate hot water. His systems produced 140°F water for up to 18 months after being built before the woody material was completely broken down and ready to use as a soil input.

By the mid-1970s Jean Pain turned his focus toward generating natural gas with the same materials but through a completely different process. He didn't have a large need for winter heat in his climate, but he did use a lot of energy for his farm equipment, vehicles, household electricity, and cooking. Eventually he was able to generate 100 percent of his farm and household energy needs through a combination of compost-powered heat and compost-powered biogas.

Jean Pain's method of biogas production was brilliantly simple and reveals one of the advantages he had as an innovative tinkerer who didn't know what was impossible.

He realized that he could produce clean, odorless, and abundant biogas by simply filling a large tank with water and partially composted wood chips. As long as the barrel was kept at a temperature of approximately 100°F, the anaerobic microbes that produce methane would be highly active.

So he simply surrounded the biogas digester (the barrel) with a large mound of shredded woody material that kept the digester warm enough to produce gas. From the top of the barrel, a small plastic tube extended up to an inflatable gas bag. Every day the gas bag partially inflated naturally, because methane is lighter than air. He would then use a biogas-powered

LEFT: *Jean Pain with his custom-made wood chipper.* CENTER & RIGHT: *The 100-cubic-yard compost-power mound, showing the inner digester, before and during the annual tear-down process.* JEAN PAIN

compressor to compress the natural gas into tractor tire inner tubes for temporary storage. The pressure from the inner tubes was enough to pressurize gas lines to his household appliances.

He then converted all of his gasoline-powered vehicles, tractors, and generators to run on natural gas (which is very easy to do), and installed a small pressurized tank on each vehicle that he would fill with his compressor. From each batch of partially composted woody feedstock placed into his digesters, he received continuous and steady daily gas production for approximately five months, after which time he uncovered the digester chamber and reloaded it as needed.

But Jean Pain was not done innovating yet. He tested using his finished compost on his crops and determined that it had a stronger fertility factor than other compost, or conventional chemical fertilizers. This went against conventional compost science in a major way: His compost had almost zero nitrogen in the original feedstock, as wood is nearly 100 percent carbon. Most compost is to this day produced with large inputs of high-nitrogen materials, such as manure and food scraps. Jean Pain documented significant crop-yield increases when he used his wood-based compost and also documented that crops fertilized and mulched with this material required much less water.

He had his compost tested by scientists in Belgium, who determined, to their surprise, that it had very high nitrogen content even though he never added any nitrogen-rich material to it.

Jean Pain and his Belgian collaborators concluded that during the long compost cycle of shredded woody materials, when microbes are constantly respiring (aka breathing), these microbes are actually depositing into the compost large amounts of nitrogen that they pulled out of the air. (Air is mostly nitrogen.)

After a few years of publicity and university-research collaborations in the late 1970s, Jean Pain died unexpectedly of a heart attack in 1981. And apparently his death, combined with the return of cheap oil, put his method on the cultural back burner. Despite the formation of the Jean Pain Institute by his family and collaborators, Jean Pain's innovations never really entered the marketplace other than through academic circles.

Tomatoes grow in midwinter at Jasper Hill Farm's compost-heated greenhouse.
AGRILAB TECHNOLOGIES

Imagine the local economic impact of hundreds of thousands of tons of brushwood being harvested and shredded for compost-powered heating systems in a state like Vermont that currently spends close to $1 billion per year on imported fossil fuels for hot water and winter heating.

Imagine a state like Vermont saving $1 billion per year (on a GDP of $24 billion) while also producing nearly another billion dollars in economic value from compost sales. Imagine Vermont doing this while solving the waterway pollution problems caused by fertilizing with raw manure, and also improving the health of its forests instead of clear-cutting.

So if all this compost-powered energy stuff works, how come every farmer and forester isn't doing it? As far as I can tell, this age-old question has only one answer: Because they haven't done it yet.

The longer answer can be summarized as: Because farmers and foresters do things how they do them; because they've invested in certain approaches and infrastructure that aren't flexible enough to make quick changes (and their infrastructure debt may not be paid off yet); or because they just haven't done it yet. The story of this evolution of ecological economics is the story that we have to tell by living it.

Chapter 3
The Science of Compost and Heat Recovery

There are many different opinions out there in academic and professional circles about the best ways to make compost. Some will say you need the right ratios of high-carbon and high-nitrogen materials. Others will say it doesn't matter what you start with; any biomass can be turned into good compost if it's handled the right way. Some assert that temperatures of the material should be kept between 132°F (the temperature at which pathogens and weed seeds are killed) and 140°F, and that higher temperatures can reduce beneficial microbial and fungal cultures.

Steaming rows of compost. HIGHFIELDS CENTER FOR COMPOSTING

Conventional compost wisdom usually asserts that you can't make good compost by using only a high-carbon feedstock like wood chips, because there's no nitrogen. Jean Pain and others claim that the aerobic respiration of the microbes composting a pure woody material actually pulls nitrogen in from the air and fixes it into the humus, giving a balanced carbon/nitrogen ratio without any nitrogen being in the feedstock.

There are lots of different microbial cultures and biological reactions going on inside materials as the compost process unfolds, depending on the kind of material and how it's handled. What about the value of fungal culture in compost? There are many ways to make yogurt or sourdough—

many different cultures, materials, and resulting subjective/objective qualities. Compost is similar: There are lots of different approaches that can work.

The preconditions necessary for the thermophilic (heat-generating) composting process to take place in any biomass material are:

1. **Water:** Dry material will not rot because the microbes that create the process require water like any other living organism. However, too much water in certain materials can make it difficult for the microbes to breathe.

2. **Air:** Composting is an aerobic process that requires air being available to the microbes throughout the material. Conventional compost-production techniques usually involve regular mechanical stirring and turning of the material to give the microbes access to air. Even with mechanical stirring, however, dense materials like food scraps and manure sometimes make it difficult to achieve good, even aeration. Most compost producers amend these kind of materials with "bulking agents" such as wood chips, bark mulch, sawdust, or straw. In large compost-production facilities the mechanical tumbling requires expensive, heavy equipment. However, recent innovations in material handling and aeration engineering have resulting in compost-production techniques that do not require tumbling of the material. Active aeration of compost usually means that air vents or ducts in the floor of a composting

Turning compost at Highfields Center for Composting. HIGHFIELDS CENTER FOR COMPOSTING

area are used to pull or push air through the material with a blower or fan. Passive aeration can also be achieved by the use of aeration tubing in the floor of a system, without a fan. *Both active and passive aeration can allow the elimination of stirring or turning, and this opens up many opportunities for heat recovery.* Aerated static (not stirred or turned) piles can also develop fungal cultures that have many benefits in terms of compost quality. The Agrilab and UVM systems explained later in the book are prime examples of how aerated static compost systems enable heat recovery as well as odor reduction.

Steaming compost on an aerated Isobar heat-recovery pad AGRILAB TECHNOLOGIES

3. **Texture relative to aeration:** For wood-chip-based systems, the right texture of the biomass is important: Large dense chunks of wood will not compost well, because the microbes and air cannot access the material inside the blocks. To quickly compost woody materials and generate high heat, it's best to use small-diameter wood chips, double-ground wood chips that have a stringy bark mulch texture, or mixtures of wood chips with materials such as mill shavings or sawdust. Woody material of a proper texture can be composted without active aeration, because the material is permeable to air, which enables passive aeration. This is why the Jean Pain method works. Manure and food scraps tend to be dense and heavy, so compost systems that use these feedstocks need either active aeration systems or regular stirring or turning of the material, as well as the addition of carbon-rich bulking agents such as bark mulch, sawdust, wood chips, straw, and so forth.

Steaming compost being tumbled for aeration HIGHFIELDS CENTER FOR COMPOSTING

Karl Hammer

Karl Hammer of Vermont Compost.
KARL HAMMER

The founder of Vermont Compost in Montpelier, Vermont, Karl Hammer has used modified versions of the Jean Pain method to extend greenhouse production through many winters at his operations in Vermont and upstate New York. His primary goal has been to extend the growing season into November and start six to eight weeks earlier in the spring than he would otherwise, as well as to heat seedbeds in his greenhouse to test his high-value potting soil mixes.

Hammer's approach has been simple and effective at keeping his small hoop house productive for his own food needs, with minimal infrastructure investment. If you ask him, "Why don't you expand your greenhouse operations and make that part of your business?" he'll most likely tell you he hopes to get to that someday but his focus is really the art of quality compost production.

Hammer got help from several people in the Compost Power Network for simple heat-recovery projects at his facility in Montpelier. Instead of installing an elaborate radiant floor heating system or air-duct system into the seedbeds, he simply uses compost-heat recovery to keep a large tank full of hot water inside the greenhouse. The tank is connected to a circulation pump that moves cooler water from the bottom of the tank through hundreds of feet of tubing inside a large composting windrow of

Hammer's windrow-style compost power mound, with one side wall held up by cattle panels
COMPOSTPOWER.ORG

This 400-gallon water tank is kept above 100°F by water circulating through the mound. COMPOSTPOWER.ORG

Hammer's compost-heated seedbeds are used to test his potting soils. COMPOSTPOWER.ORG

bark mulch, pushing hot water into the top of the tank.

The tank constantly bleeds heat into the greenhouse, providing a thermal bank and a passive source of heat through the winter nights. Hammer waters his plants, sometimes through drip irrigation, sometimes just with a hose, with the 70 to 80°F water from the "cool" side of his compost heat loops. He has a second water line from the tank to supply a simple radiant floor loop buried in seedbeds.

Hammer uses shredded bark mulch as a primary input to his compost production, blended with other materials. Bark mulch mounds that are large enough often stay hotter than 140°F degrees for more than six months, even without being stirred or tumbled, because the texture enables airflow to happen passively.

In some of Hammer's earlier experiments his greenhouse was located on a slight hill. He sited the compost power mound downhill from the greenhouse and oriented the tubing in the compost to enable hot-water circulation without a pump via the thermo-syphon effect: As long as the tubing rises continually, the heat continually rises until it reaches the water tank, causing circulation; this also pulls cooler water from the bottom of the tank back into the cool/supply side of the compost heat-exchange loops.

4. **A balance of moisture and air:** If a material is dry, or is not permeated with airflow, the microbes will not build up an active culture and the material will be preserved instead of rotting. No rot = no hot. But if a biomass material of the right texture contains enough water and enough airflow, a thermophilic microbial culture will quickly bloom and generate very high sustained temperatures until the biomass is completely digested by the microbes, or until the air or water is no longer available to sustain the microbial culture. Access to air is created in a variety of ways including mechanical tumbling of the material and passive or active aeration.

Part of what's going on during the composting process is the oxidation of carbon by bacteria. For this to occur quickly and generate large amounts of heat, the bacteria need enough food: carbon and nitrogen, oxygen and water. With primarily wood-based feedstocks that are mostly carbon and very little nitrogen, the bacteria seem to get their nitrogen from the air, and that nitrogen eventually gets "fixed" into the finished compost. This is an open and ongoing debate among compost experts.

The temperature gauge at an early CompostPower.org project, Hartshorn Farm in Waitsfield, Vermont.
COMPOSTPOWER.ORG

A wood chip will only have a large volume of thermophiles (thermophilic bacteria) on its outer edges or surface. The food/carbon inside the chip is not accessible until the outer edges break down. This is why the Jean Pain method works best with a stringy shredded texture of woody material, or a blend of wood chips and sawdust.

The lignins and cellulose in wood chips and sawdust are complex carbon molecules that resist decay. But that slow breakdown process is great for steady base-load heat production, as Jean Pain discovered. The more gradual

oxidation produces an extended thermophilic condition that can create temperatures of 140°F or more for up to 18 months in large compost piles. (Pain, 1979)

Now let's talk about manure. Horse manure with straw bedding is often considered a premium material for compost-heat recovery because it's easy to handle and rapidly releases heat and CO_2. Straw or hay bedding breaks down quickly, and it absorbs nitrogen-rich urine (even more than sawdust does). Nitrogen is an important building block of amino acids that form new cell protoplasm in bacterial cultures. The bacteria then feed on the carbon in the compost, absorbing oxygen and releasing heat and CO_2. (Fulford/NAI)

Fulford's report about the NAI compost-heated greenhouse goes into detail about various feedstocks for compost:

> **At the stables where we get the manure, it has already been mixed with sawdust bedding that has frequently risen above 120 degrees F (49°C) when we load it. We have had good thermal production from this mix, sustaining temperatures between 120 and 170 degrees F (49–77°C) for four weeks or more. Because the mix contains a high percentage of unavailable carbon, only a small fraction of the mass is actually involved in active oxidation at any given time, and therefore this mix has a relatively low heat production capacity per volume per day when compared with a mix like horse manure and urine bedded with straw. (Fulford/NAI)**

Poultry manure can generate a lot of heat and has high levels of nitrogen and phosphorus. Like other manure-based composts, poultry manure is usually mixed with carbon sources such as sawdust, hay, or leaves to produce a compost that is porous, absorbent, and of a good carbon/nitrogen ratio on the input side of the equation. NAI's experiments with poultry-based feedstocks for compost-heat recovery showed promising results with the ability to heat up to 140°F within a few days. "We have experimented with everything from quail and pheasant manure from the state game farm to camel and elephant dung from the circus that comes to the county fairground each summer." (Fulford/NAI)

Compost bulking agents are needed when the primary feedstock is high

Bruce Fulford

Bruce Fulford could in many ways be described as the New England version of Jean Pain. He's been a respected and accomplished compost scientist and agricultural entrepreneur since the late 1970s and has been involved in much of the compost-heat-recovery work done in the United States.

In the 1980s Fulford worked with the New Alchemy Institute to build and operate North America's first commercial-scale compost-heated winter greenhouse. Over the years he has also conducted many tests and studies with actively aerated compost systems.

The hot, steamy CO_2-rich air from the compost in the NAI project was pumped into the soil under seedbeds in the greenhouse. The thick layer of compost and soil acted as a biofilter to reduce any obnoxious odors or gases such as ammonia. This method also dramatically enriched the CO_2 levels in the soil and the greenhouse air. Greenhouses often aim to have a CO_2 level three or four times the normal level of 390 parts per million (PPM), to increase crop yield.

Although the air temperatures of the NAI greenhouse dropped during cold weather due to greenhouse design flaws and air leaks, the soil temperature was kept at ideal conditions throughout the winter.

"Soil temperatures in the composting greenhouse have consistently been higher than those in the other greenhouses at New Alchemy. Soil in the upper bed (on top of the compost chamber) [has] averaged 75 to 80 degrees F (24–27°C) when the compost temperatures averaged 130 degrees F (54°C). These are ideal conditions for seed germination, propagation, and for bedding plants." (Fulford/NAI)

Bruce Fulford of City Soil Boston
BRUCE FULFORD

Fulford with students at City Soil greenhouse BRUCE FULFORD

The NAI's experimental compost-heated greenhouse incorporated several innovative designs, including an insulated composting chamber across the entire lower half of the northern wall. This chamber had a built-in air-duct system with small ventilation fans used to pump hot CO_2-rich air out from under the compost and into a thick biofilter of compost underneath the seedbeds.

The concept brought three important innovations to winter greenhouse operation:

1. It allowed operators to make quality compost in a labor-efficient way in close proximity to where the compost would be used.
2. It kept the soil in the greenhouse warm enough to grow crops throughout the winter.
3. It provided CO_2 and other nutrients to the roots and leaves of the crops as they were growing.

The New Alchemy Institute's compost-heated greenhouse that was operated in the mid-1980s by Fulford and others
BRUCE FULFORD

The NAI greenhouse was run for a couple of years as a research project. The compost kept the soil above 70°F throughout the cold winters of Cape Cod. The greenhouse air temperature dipped below 40°F on the coldest nights, but that is tolerable for certain crops.

"It was used until the greenhouse fell down, for about seven years as part of the farm operations," said Fulford. "The framing materials were made of recycled lumber and eventually fell apart, and the NAI . . . eventually closed as well. The weak link in that system was the reliance on manual labor for loading and unloading of the compost. It was more about proof of concept than a long-term operation." (Fulford interview)

Fulford's UVM greenhouse heating test that began in 2012 is in many ways an attempt to continue

The Horticulture Farm at UVM is a working farm that has student programs and classes built into its operation.
AGRILAB TECHNOLOGIES

The aerated compost bin at UVM's compost-heated greenhouse.
AGRILAB TECHNOLOGIES

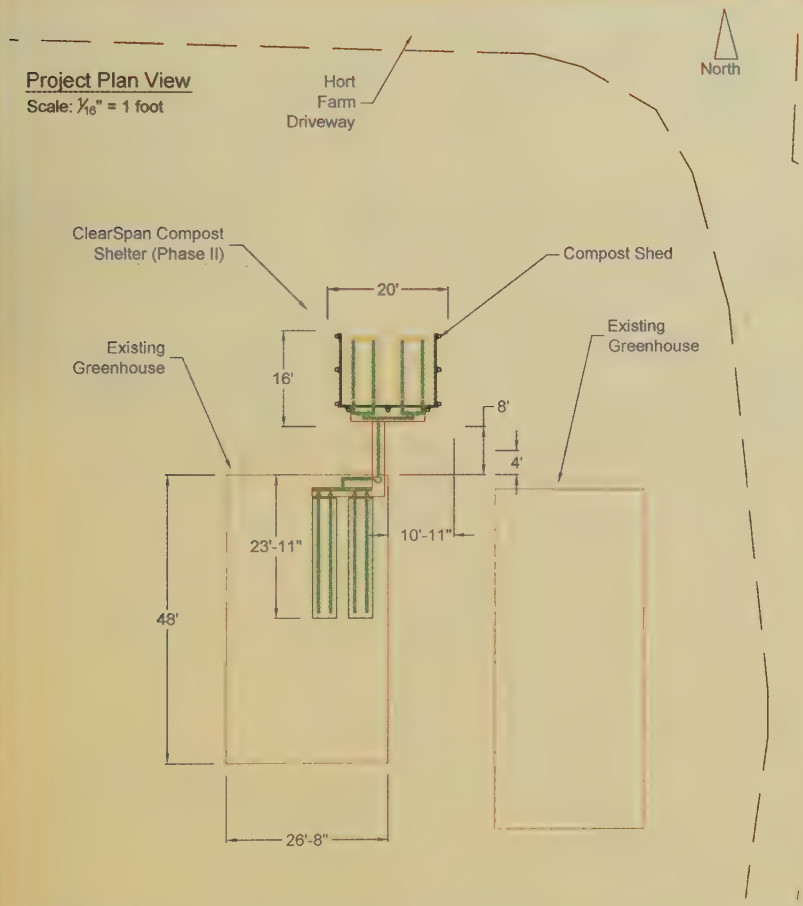
what was learned from the NAI compost-heated greenhouse while taking the research to the next level. "For a university-based research project it's a pretty good manageable size, but a more commercially viable approach would likely be larger-scale," said Fulford. "Where my efforts are going now is getting compost operations up and running where there's also alignment to operate greenhouses that can be heated with the compost over a long term so that proper investments can be justified. Often the skill sets required to build and operate winterized greenhouses are not a focus of compost producers and farmers, so finding locations and projects where all of these variables come together has been a challenge.

"Before I was at NAI I did a few projects that led to the NAI greenhouse. I did projects in Maine and New Hampshire with greenhouses and a number of prototype compost-heat-recovery designs that were later improved upon with the NAI design." (Fulford interview)

The NAI researchers concluded that heat recovered from compost in this way could be a viable stand-alone approach to winter greenhouse heating if the greenhouse is properly air-sealed and well insulated, or if larger compost volumes are used.

In 2011 Fulford, in collaboration with several people from the Compost Power Network and Agrilab Technologies, embarked on a new research project with the University of Vermont. The three-year project was funded by UVM's Clean Energy Fund, which comes from a small fee each student pays each year.

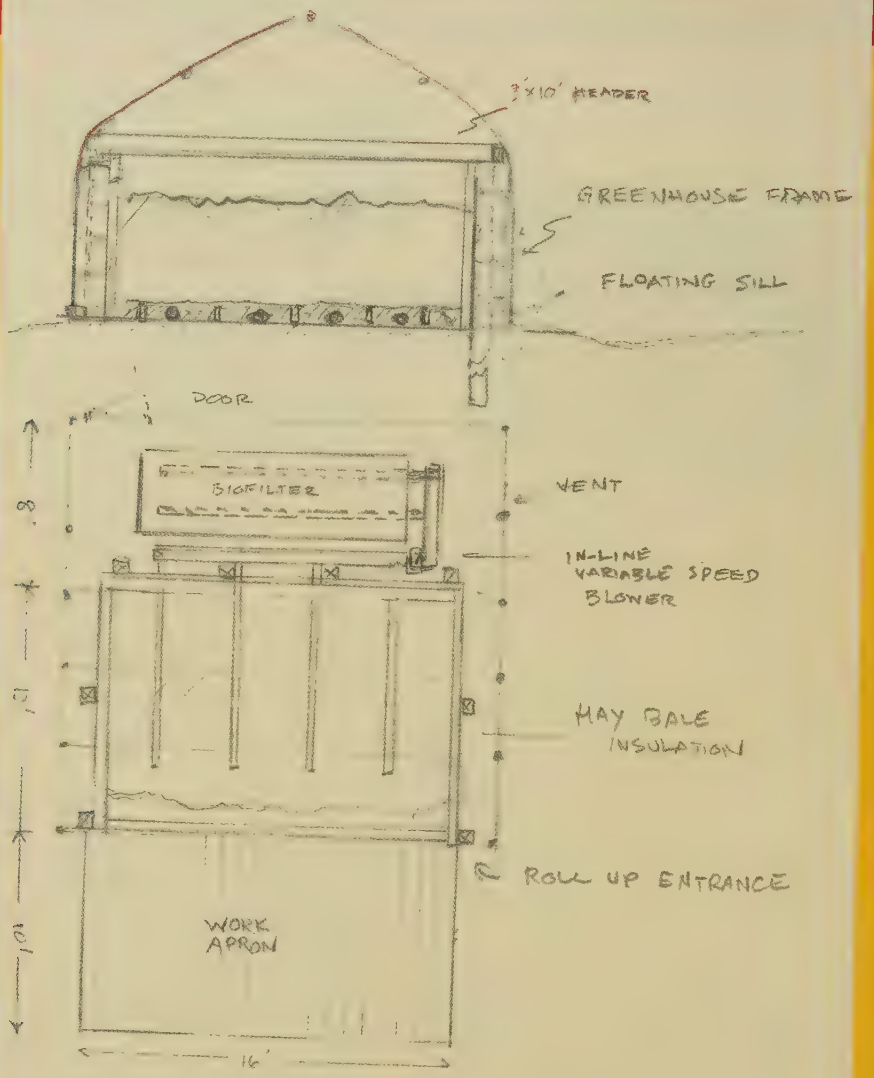
BRUCE FULFORD



Drawing of UVM Hort Farm compost-heat-recovery compost bunker

Michelle Smith, an administrator with UVM, was the project manager for both the Slade greenhouse and the second year of research at the Hort Farm, with Bruce, Jason, and myself as project consultants for the design and construction of each project.

The focus of the UVM research mirrors the NAI greenhouse in concept. But instead of the north wall of the greenhouse, the compost-

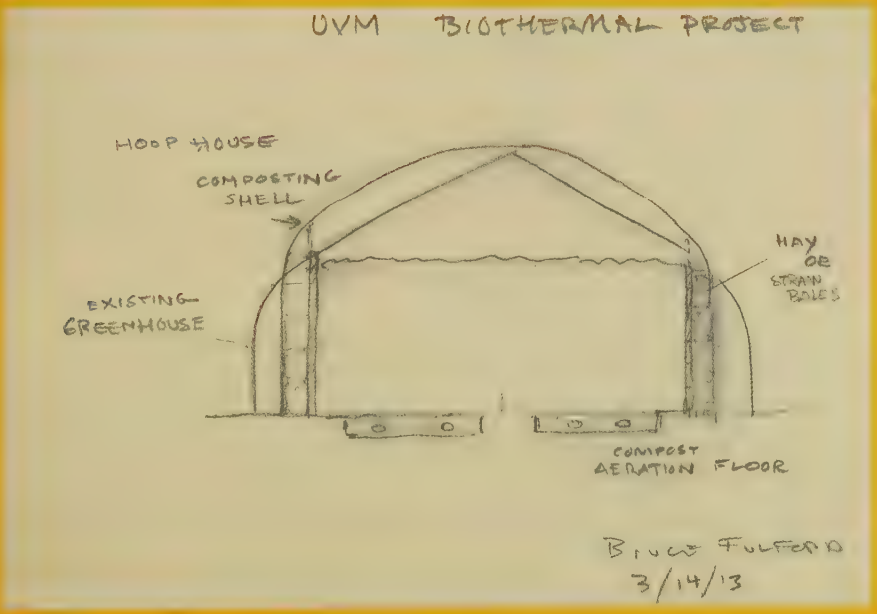


ABOVE & RIGHT : *Drawings of compost-heat-recovery bunker and greenhouse with compost-heated seedbeds at UVM Hort Farm that enables a fan to pull hot steamy $C0_2$-rich air down through the compost and into the biofilter seedbeds in the adjacent greenhouse.*

UVM Hort Farm compost-heat-recovery aeration tubes in the floor.
AGRILAB TECHNOLOGIES

Compost-heat-recovery ductwork in the greenhouse channels hot steamy air directly into a biofilter of mature compost under the seedbeds.
AGRILAB TECHNOLOGIES

BRUCE FULFORD



Aeration fan that pulls hot compost vapor out of the floor of the compost bunker and into the seedbeds at the UVM Hort Farm project
AGRILAB TECHNOLOGIES

Compost-production area at Highfields Center for Composting
HIGHFIELDS CENTER FOR COMPOSTING

Electrical and monitoring controls at the UVM Hort Farm's compost-heated greenhouse
AGRILAB TECHNOLOGIES

in nitrogen and low in carbon, or when material is exceedingly wet. Many feedstocks such as manure, food scraps, and slaughterhouse or fishery wastes need to be mixed with other carbon or nitrogen sources, then mechanically blended and stirred to compost properly. One method of adding bulking agents to wet manure is to use sawdust, straw, or wood chips as bedding in barns, letting the animals do the mixing with their feet in what is known as a "bedded pack" approach. Manure mixed with bedding and nitrogen-rich urine usually composts well.

production bay is built next to the greenhouse.

The UVM research compost bay is a 16-foot-wide, 16-foot-deep, and 10-foot-tall wooden box with one side open. Build into the dirt floor are four perforated 4-inch PVC pipes connected to ductwork that goes underground and into the adjacent greenhouse.

In the greenhouse the main duct splits into four smaller perforated ducts that each go underneath a row where plants are grown. On top of this perforated ductwork is a 24-inch layer of fluffy mature compost capped with topsoil. This thick layer of mature compost will serve as the biofilter to prevent ammonia or other odors from the manure from entering the greenhouse air, while holding a lot of heat that is blown in from the compost aeration systems.

A single 150-watt Fantech ventilation fan operates the entire UVM system by pulling air down through the compost into the perforated pipes in the compost bay, moving hot steamy air through the ductwork into the seedbeds.

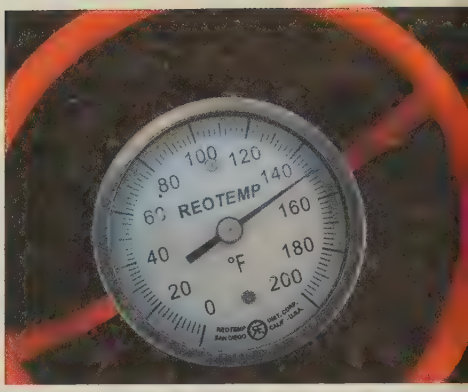
Sensors are placed throughout the system, tied to a web-based data logger that tracks all the key metrics of the system. Sensors placed in the air near where the plants are growing will also track CO_2 (which they want to maximize) and ammonia (which they're hoping the biofilter keeps to a minimum).

Fulford is considering a similar system on a much larger scale that includes the Agrilab Isobar system, to heat the City Soil greenhouses in Boston where he operates a commercial compost-production business. In that system the hot steamy air would run through an Isobar heat exchanger, making hot water for radiant floor/seedbed heating loops. The air exhaust from that system (80 to 90°F typically) would then be directed into a small biofilter in the greenhouse, which would add supplemental heat and valuable CO_2 to the air.

In many compost-production operations too much moisture results in water and nutrients running off while preventing airflow through the pile, creating potential environmental issues. This indicates the need for more bulking or carbon, which can absorb the water and put it to good use as a foundation for microbial culture.

The best moisture level for composting is from 45 to 65 percent. One of the main issues requiring management and monitoring in compost production, particularly when compost-heat-recovery methods are used,

Steaming "bulking agents," in this case wood chips, at Grow Compost in Middlesex, Vermont AGRILAB TECHNOLOGIES



A compost thermometer
COMPOSTPOWER.ORG

Compost is turned with a bucket loader to aerate the material. HIGHFIELDS CENTER FOR COMPOSTING

is to maintain adequate moisture levels.

Well-aerated systems tend to dry out the material, which sends the microbial cultures into a stall or hibernation mode if they run out of water. High-carbon bulking agents help to hold and distribute moisture. One of the innovations that came out of the Compost Power Network was to use hay bales as insulating side walls of Jean Pain–style systems, as well as a thick top coat of loose hay, specifically because this helps retain moisture that would otherwise steam off the system.

Materials that mat easily, such as wet leaves that have not been shredded and blended with other materials, require turning and thus more labor than fresh horse manure with straw bedding. When straw or sawdust bedding is mixed with manure, distribution of moisture and air to the material is maximized. Many materials can be layered successfully, or mixed prior to loading. Labor and/or equipment considerations must be addressed when choosing a feedstock that requires the mechanical addition of a bulking agent. (Fulford/NAI)

Chapter 4

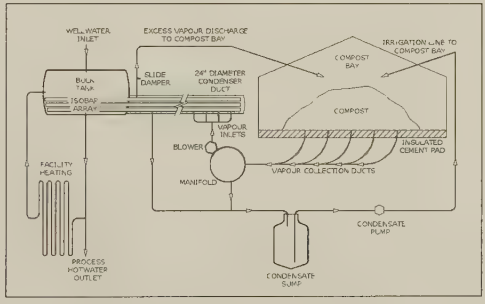
Large-Scale Isobar Systems

The Agrilab system uses a patented Isobar method of vapor-based heat exchange. Essentially, air, steam, and vapor are pulled out of large manure or compost piles and run through a patented heat exchanger. The airflow system also actively aerates the compost, which in effect turbocharges the microbial culture without the manure needing to be stirred or turned, as is typical in manure-based compost production.

The use of active aeration systems and elimination of the process of regular mechanical turning of compost is an enormous step forward in compost production efficiency all by itself.

Most of the aerated static pile compost systems use positive aeration, blowing air into the compost from the ground up. One of the Agrilab innovations is to instead pull the air down into perforated ducts in the ground or floor underneath the compost. This is known as negative aeration and has a few very important benefits.

If you're going to be using energy to move air through compost, capturing heat from that airflow to make the system net positive in terms of energy production is a no-brainer.



Engineering schematic showing how the Agrilab Isobar compost-heat-recovery system works. AGRILAB TECHNOLOGIES

The Isobar aerated compost pad at the University of New Hampshire's Organic Dairy Research Farm. AGRILAB TECHNOLOGIES

Agrilab Technologies

The Isobar compost-heat-recovery system was brought to market by Brian Jerose of Agrilab Technologies, who developed the first system installed at Diamond Hill Custom Heifers in Sheldon, Vermont, in 2005. He collaborated with Joe Oullette of Acrolab Ltd. to develop the heat-exchange system. Acrolab is a Canadian company that specializes in industrial heat exchange.

Jerose worked with Joe Oullette to adapt his existing Isobar system to capture heat from compost. Oullette is the inventor and patent holder of the Isobar compost-heat-recovery technology. He built a test system at his Toronto office in 2003 and successfully heated a small greenhouse with energy captured from compost.

In 2009 Josh Nelson teamed up with Brian Jerose as a partner in what would become Agrilab Technologies, LLC, which has an exclusive license to the Acrolab patent and trademarks related to the Isobar system. Nelson accelerated the project development work and helped to get three additional projects to happen.

Josh Nelson, partner in Agrilab Technologies. He passed away in 2012; RIP. AGRILAB TECHNOLOGIES

Jerose brought more than a decade of experience offering compost technical services to farms and compost producers. He was instrumental in developing several new Isobar projects including Sunset View Farms in New York State, as well as Jasper Hill Farm in Vermont and the University

Brian Jerose, founder of Agrilab Technologies BRIAN JEROSE

Josh Nelson at the construction of the compost-heat-recovery building at Jasper Hill Farm AGRILAB TECHNOLOGIES

The first Agrilab Isobar compost-heat-recovery project at Diamond Hill Custom Heifers was an extensive collaboration among companies, non-profits, and government agencies.
COMPOSTPOWER.ORG

of New Hampshire dairy farm in Durham, New Hampshire.

In early 2012 Josh Nelson died unexpectedly from a brain aneurysm, just as Agrilab was gaining very strong momentum. In the year that followed, Jerose reorganized the company, expanded the team, and—as of this writing—has developed a long list of potential projects as he searches for venture capital to expand the reach of the company. I am serving as a consultant to Agrilab to help the company scale up the reach of the Isobar system while also offering customized design-and-build services for modified Jean Pain–style systems to clients all over the world.

The history of Agrilab Technologies is interesting in itself. It all started in 2001 when Brian Jerose met people from Acrolab at a Biocycle composting symposium. Brian later explored compost-heat-recovery projects with the Acrolab technology in mind for several potential projects, while collaborating with Bruce Fulford who was still doing experimental compost-heat-recovery projects based on what he'd learned in the past.

In 2004 Jerose worked with Terry Magnan, owner of Diamond Hill Custom Heifers, to apply for grants that were awarded in 2005. A USDA NRCS Conservation Innovation Grant (CIG) and Vermont Alternative Manure Management Program grants were awarded, covering most of the project costs.

The Isobar system and new compost production facilities were installed in late 2005. In 2009 USDA REAP funds were awarded to Sunset View Farm, on their second application, and the system was installed in 2010. In 2011 and 2012 Jasper Hill Farm and the University of New Hampshire's Organic Research Dairy Farm contracted with Agrilab to install Isobar compost-heat-recovery systems.

Using negative aeration makes heat recovery possible, because you're pulling out of the compost hot steamy air, which can then be run through heat exchangers or biofilters.

Another benefit of negative aeration is the ability to reduce or eliminate odors. Since air is constantly being drawn down into the compost, odors tend to get pulled into the material. The exhaust from this ventilation process, regardless of whether a heat exchanger is used, can be run through various types of simple biofilters to remove any potential odors caused by compounds commonly found in compost, such as ammonia.

The Isobar system was originally developed and patented by Joe Oullette of Acrolab, a Toronto-based leader in industrial heat-exchange systems for more than 50 years. The solution was brought to market by Agrilab Technologies of Vermont as a licensee of the intellectual property behind it. Since the first system was installed in 2006, several others have been brought online at farms ranging in size from 50 cows to 2,000—but they can be scaled up to any size. The technology has proven itself to be an economically viable form of water and space heating along with being an energy-efficient process for large-scale composting facilities.

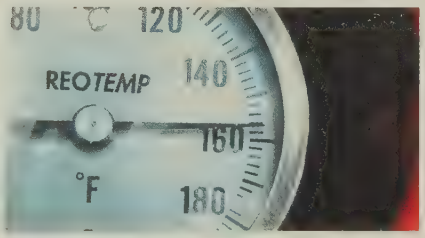
Sunset View Farm's compost-heat-recovery building. Note the wood chips covering the aeration channels in the floor and a steaming row of compost loaded on one side.
AGRILAB TECHNOLOGIES

For farm applications of compost production and heat recovery, the first task is to understand feedstock volumes available from farming operations. A 1,000-pound dairy cow produces 75-plus pounds of manure per day, or about 2,500 pounds of manure plus bedding per month.

A compost-heat-recovery system can capture 1,000 to 1,500 Btu/hr continuously for four or more weeks from the manure produced by that one cow. So a farm with 200 dairy cows could consistently produce 200,000 Btu/hr if all of its manure is managed through a compost-heat-recovery system. This amount of energy equates to more

Joe Oullette, inventor of the patented Isobar compost-heat-recovery system, inspects the heat exchange array at Sunset View Farm in New York. AGRILAB TECHNOLOGIES

than $20,000 of fuel savings over a six-month period.

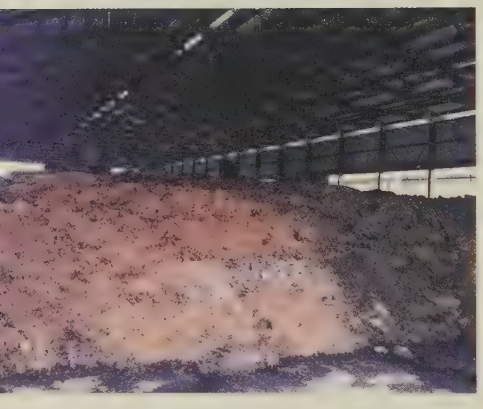


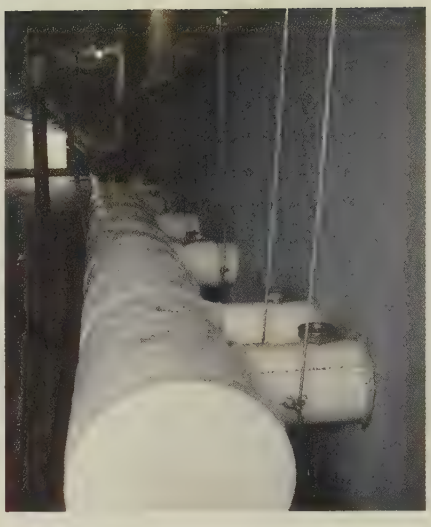
A compost thermometer
COMPOSTPOWER.ORG

Diamond Hill Custom Heifers in Sheldon, Vermont, installed North America's first large-scale Isobar compost-heat-recovery system in 2006. The farm raises several hundred calves each year in a clean climate-controlled environment, primarily for regional dairy farms. A bedded pack manure management system and compost-heat recovery are key elements of the operation's reputation for maintaining optimum calf health.

Steaming compost at Diamond Hill Custom Heifers. AGRILAB TECHNOLOGIES

The system captures an average of 200,000 Btu/hr continuously from 150 to 200 tons of manure and bedding feedstock in the adjacent compost-production area. The peak water temperature output of the system is 146°F. Much of the heat goes toward radiant floor and hydronic heating





TOP LEFT: *The indoor radiant-floor-heated calf dormitory at Diamond Hill Custom Heifers.* COMPOSTPOWER.ORG

TOP RIGHT: *Agrilab Technologies' compost aeration ductwork* AGRILAB TECHNOLOGIES

LEFT: *The compost-heat-recovery building at Diamond Hill Custom Heifers, fully loaded with 200 tons of manure and bedding* COMPOSTPOWER.ORG

systems in the adjacent barns and buildings, as well as for wash water for the farm.

The project included construction of new composting and storage buildings as well as a feedstock mixer, with the Isobar system making up less than $80,000 of the $480,000 total project cost. Much of the project was financed by public and private grants, which enabled the farm to install buildings and other infrastructure that wouldn't necessarily have been required for the compost-heat-recovery system to function.

Two Lester-style buildings were constructed for the compost-production area, utility rooms, and feedstock curing/holding areas. These are in essence pole barns with concrete slab floors and retractable side walls for seasonal ventilation. Less than half of the building space was actually used for the compost operation and heat-recovery system; the rest is available for future expansion.

A barn at Diamond Hill Custom Heifers COMPOSTPOWER.ORG

The feedstock, which is the bedded pack manure and sawdust that is built up and periodically removed from the barns, is blended to a consistent texture optimal for composting with a Kuhn Knight vertical feed mixer that cost $33,000. This equipment makes it easy to process up to 30 tons of material per hour, enabling the 200-ton compost production area to be cleared out and refilled in less than one workday with only one equipment operator.

The only moving part in the Isobar system is four 10-inch 0.25-horsepower Fantech blowers that aerate the compost and pull hot air through the Isobar heat-exchange system.

The system processes approximately 1,600 tons, or 3,200 cubic yards, of manure/bedding feedstock per year, producing 1,600 cubic yards of compost in that time. Annual compost sales revenue exceeds $25,000; some is kept for on-farm fertility needs.

The farm primarily uses the compost-heat-recovery system in winter months for space heating and saves more than $10,000 per year on energy costs. The $60,000 cost of the Isobar and compost ductwork system can be seen as having paid for itself through energy savings alone in just six years and should continue operating with minimal maintenance for decades to come. The farm also calculated saving $19,000 per year compared with labor costs associated with prior methods of manure handling.

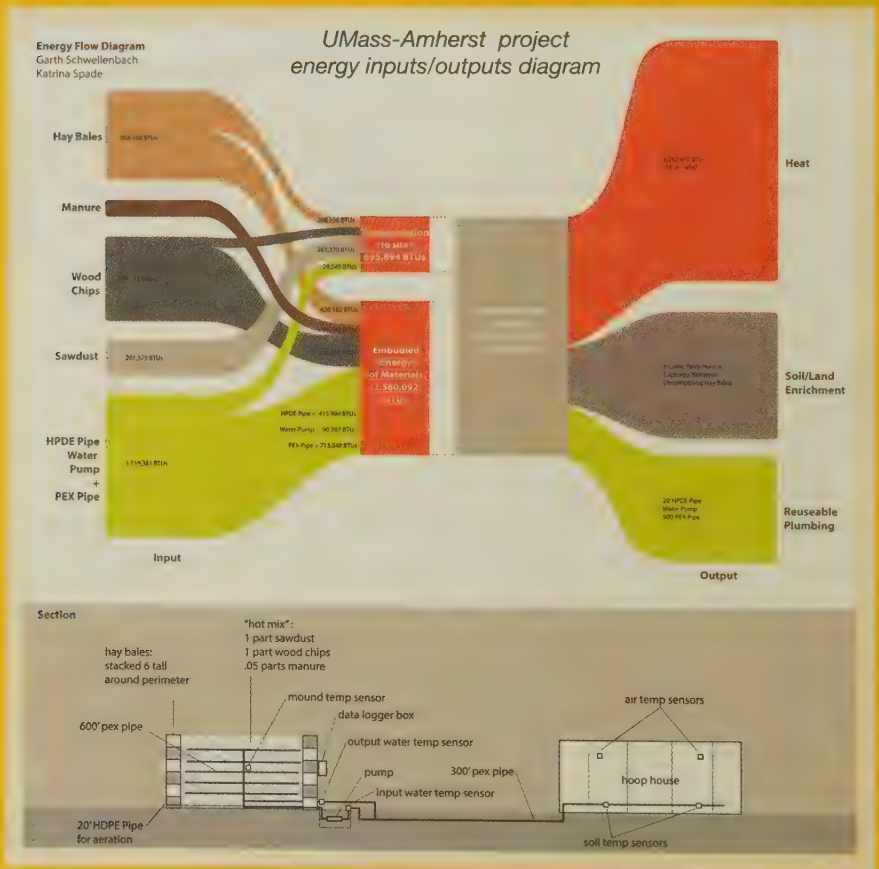
University of Massachusetts–Amherst

Graduate Thesis Project

In the autumn of 2012 Garth Schwellenbach and Katrina Spade—graduate students in architecture at UMass–Amherst—began a compost power project as part of a sustainable design certificate program in collaboration with Yestermorrow Design/Build School.

Their design was similar to other modified Jean Pain systems described elsewhere in this book and was funded by a grant from the university. To complete the project Garth and Katrina teamed up with Jesse Selman of the Potwine Neighborhood Farm—a local farmer who had large piles of brushwood available, and a desire to learn about compost and compost heat recovery.

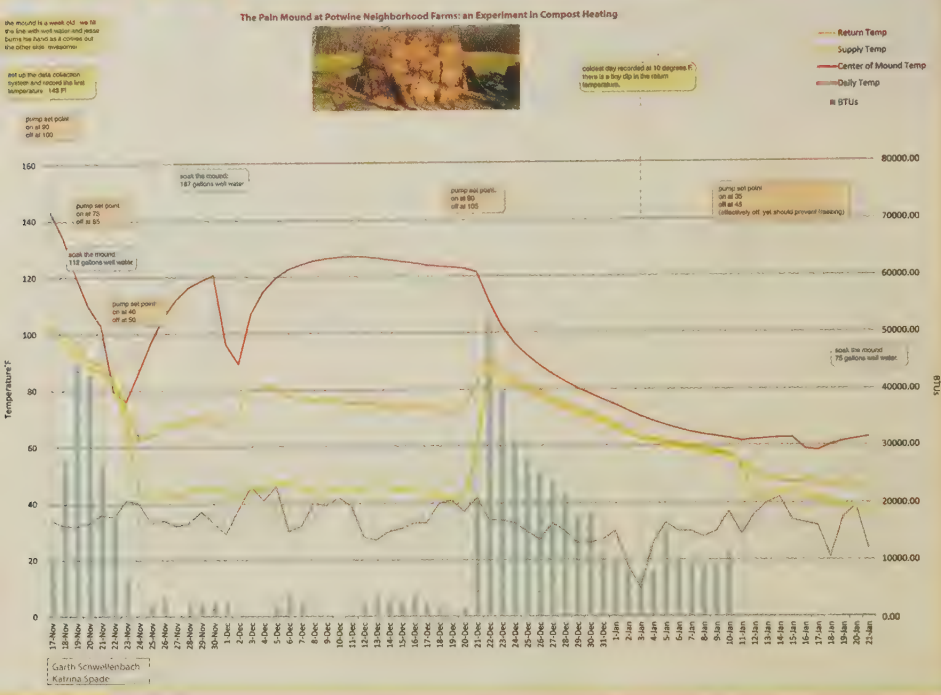
They used hay bales as insulating side walls, and 100 feet of perforated 4-inch tubing for aeration in the



GREEN MOUNTAIN TECHNOLOGIES, INC

Images showing the step-by-step construction process used for the UMass Amherst project.

GARTH SCHWELLENBACH



UMass–Amherst project energy inputs/outputs diagram

base. Garth rented a wood chipper and ground up about 10 cubic yards of brushwood to serve as their primary feedstock, while mixing in about 10 cubic yards of sawdust and 1 yard of manure/bedding with the wood chips as the system was built. They built half the wall of hay bales and used that as a backstop, pointing the machine so that the chips were blown into the mound as the brush was chipped, with about 900 feet of 1-inch PEX tubing distributed throughout six layers inside the mound. They added 112 gallons of water to the material as the mound was built (far too little, it turned out).

The original plan was to use the hot water circulated through the poly tubing to heat radiant loops in the seedbeds of a greenhouse. However, the greenhouse was not complete in time, so they simply circulated the water through about 200 feet of poly tubing that was laid out on the ground and covered in hay (essen-

Sunset View Farm, New York. Sean and Sandy Quinn, owners of the 2,000-cow KA Sunset View Farm in Schaghticoke, New York, installed an integrated composting and thermal energy system in late 2010 and documented the construction, start-up, and initial operation period.

tially wasting the heat as the system was tested).

The temperature of the mound began around 140°F. The circulation of cold water was set at 2 gallons per minute for the first week, and the temperature of the mound immediately dropped to 80°F. Garth and Katrina eventually realized that this circulation rate was too high and tried a few different speeds. Once they set the circulation at 0.5 gallon per minute, the mound temperatures recovered to 120°F-plus for the next six weeks into the end of December, yielding significant Btus as calculated based on the supply/return temps of the circulating water.

At that time the temperature of the mound dropped again. Further investigation showed that the material had become dry, which stalled the composting process. This amount of material should have been soaked with at least 1,000 gallons of water to keep the material from steaming itself dry over time. Attempts were made to resoak the material in midwinter, along with adding "shit tea" made from chicken manure, which helped. Still, the cold weather and stalled biology of the process made it difficult for the system to recover to its former high temperature. When warmer weather arrived in the spring the temperature of the mound recovered to the 120°F range.

This project reinforced a lesson taught by other systems: Adding enough water is essential, and it's pretty difficult to kick-start a system that has stalled from drying out in the middle of winter.

Garth and Katrina did a fantastic job of tracking all the inputs to their project in terms of material cost, man-hours, and energy used, as well as Btus captured. The water temperature of their hot-water line from the system was significantly lower than the temperatures of the internal areas of the mound, because they placed the sensor on the water line that was already outside exposed to the open air, so their Btu calculations were not accurate. Similarly sized systems operating with a 0.5-gallon-per-minute flow rate while maintaining internal mound temperature of 120°F-plus have been documented at 10,000 Btu/hr, which would have amounted to more than 7 million Btus per month, or $210 of propane savings.

The farm is using an Isobar Heat Recovery Unit from Agrilab Technologies to capture the vapor from active manure-composting bays as renewable thermal energy. The farm and Agrilab Technologies prepared a case study for the New York State Energy Research Development

Compost on aerated heat-recovery pad at Sunset View Farm AGRILAB TECHNOLOGIES

Aeration channel in the floor of a compost production pad tied into an Isobar heat-recovery system AGRILAB TECHNOLOGIES

Authority (NYSERDA) with assistance from other technical partners. NYSERDA and USDA Rural Development provided cost sharing and loans to the farm to support project implementation.

Sunset View Farm raises calves and heifers for area dairy farms. The composting and thermal energy system is located at the old Agway farmstead structure where calves and heifers are raised. A milking herd is housed on an adjacent farmstead. The manure and bedding from the calves and heifers are the primary inputs for the composting system.

Solid bedded manure from calf hutches and pens is combined with dewatered manure solids (a DODA separator is used) in batches loaded into four negatively aerated composting bays.

In-floor aeration channels are set into an insulated concrete slab to facilitate negative aeration (suction) and efficient material handling

Data collected from 2010 through 2012 represented pre- and post-implementation energy consumption on the farm. After adjusting for variables in herd size and averaging energy unit prices, the farm has realized decreased costs of diesel, propane, and electricity per animal unit. Total diesel and propane consumption also declined and was largely attributed to savings from reduced heating needs. Total electricity consumption increased due to the operation of the manure solids separator.

Heiner Cuhls

Heiner Cuhls is a compost-heat-recovery innovator based in Germany who's been doing his own research and experiments following Jean Pain's methods for several years. His company, Native Power, has installed dozens of modified Jean Pain–style systems in northern Europe, and he's also started doing workshops and projects in the United States and Canada.

His methods are similar to those used in most of the Compost Power–style projects, although he's come up with some innovative ways of containing and managing materials. He points out in his workshops that it's essential to get the woody material thoroughly soaked in water if the systems are to stay hot and active for 12 to 18 months. His websites states that he's built more than 60 systems in Europe including one that is providing hot water for a hotel in northern Germany.

In November and December 2012, the thermal energy from the Sunset View Isobar Heat Recovery Unit delivered an average of 195,000 Btu/hour or 4,686,000 Btu/day, with water temperatures at 115°F.

The system achieved peak water temperatures of 129°F and peak output of 237,000 Btu/hour and 5,695,000 Btu/day. This preheating function as a co-product of composting has saved the farm a $9,200 per year during its initial operation.

The project team has identified improvements in the compost aeration dampers that would increase the performance of the composting system and total thermal energy sent to the heat exchanger. The value and efficiency of the heated water can be improved by additional insulation and changes in feed preparation methods.

Additional savings for the farm were realized through reduced manure handling and spreading costs and considerable savings in reduced bedding purchases of sawdust and shavings.

Professor Robert Rynk from SUNY Cobleskill; Joseph Oullette, president of Acrolab Ltd in Windsor, Ontario; and Josh Nelson (1955–2012) were among many partners contributing to the project and the preparation of the case study.

Jasper Hill Farm, in Greensboro, Vermont, installed an Agrilab Technologies Isobar compost-heat-recovery system in 2012 that is integrated into a small-scale anaerobic biogas digester. This small-scale organic dairy farm produces premium cheese and is to my knowledge the smallest dairy farm in the world with a compost-heat-recovery system that is also integrated with biogas generation, showing that this advanced technology can make sense even for a dairy farm with only 50 heifers.

Jasper Hill Farm in Greensboro, Vermont, is one of the most innovative and picturesque small dairy farms you'll find anywhere. AGRILAB TECHNOLOGIES

The farm also installed a large winterized greenhouse on the south wall of the building that is entirely heated through Vermont's winter only by heat captured from compost. Once the hot air from the compost is run through the Isobar heat exchanger, the final exhaust is usually 80 to 90°F. This CO_2-rich warm air is piped into the seedbeds in the greenhouse.

The compost-production area is on the north wall of the greenhouse. This ductwork in the greenhouse is from compost aeration channels that bring steamy 140°F air to the Isobar heat exchanger and ultimately to the seedbeds. AGRILAB TECHNOLOGIES

A thick layer of compost under the top soil in the greenhouse serves as a biofilter to prevent any ammonia from getting into the greenhouse. As of this writing, the greenhouse is producing a wide variety of crops, from tomatoes, peppers, and greens to strawberries, pineapples, and even a banana tree.

The biogas digester is kept at the ideal operating temperatures of 100°F by heat captured from the Isobar system. Adjacent buildings and all the wash water for their operation are heated with a combination of using heat from compost and burning biogas produced by the digester.

Tomatoes and other produce grows in midwinter at Jasper Hill Farm's compost-heated greenhouse. AGRILAB TECHNOLOGIES

The University of New Hampshire in Durham (UNH) installed new compost-production infrastructure and an Agrilab Isobar heat-recovery/aeration system in 2012. UNH created a second dairy farm in 2007 with the support of multiple partners in order to operate a model Northeast organic dairy farm.

This facility is called the Burley-Demeritt Farm and is now also known as the Organic Research Dairy Farm (ORDF). In 2012–13 a composting facility was constructed on the farmstead in order to manage the bedded pack manure, scraped manure, and other farm residuals. Thermal energy (heat capture) was included in the composting facility using an Agrilab Technologies Isobar Heat Exchange Unit.

The initial goals of the composting and thermal energy system are to improve the efficiency of manure management practices, replace the practice of stacking and spreading raw manure, conserve nutrients (especially carbon and nitrogen), and decrease the number of loads to be field-applied, while also creating renewable thermal energy. Reduction in diesel fuel consumption (in comparison with tractor use in a turned windrow composting method) is an intended outcome from the reduced spreading.

Using an aerated composting process (negative aerated static piles or

ASP), the hot vapor that is exhausted from the compost piles is drawn through ductwork into the heat-exchange unit. Specialized heat-transfer tubes (Isobars) within the unit condense heated vapor and transfer thermal energy to a water tank. The heated water is then available to support other on-farm heating needs from washing to sanitation, facility heating, and a planned future greenhouse.

This is the fourth Isobar Heat Exchange Unit installation in the United States, and researchers intend to collect composting and operational data to assess the most cost-effective practices and share the information with farmers and compost site operators.

The research team is led by Dr. John Aber and doctoral candidate Matt Smith of the Natural Resources and Earth Systems Science (NRESS) Program. Their work is coordinated with the farm staff to integrate the operational practices with research and documentation needs of the project. Additional support is provided by Brian Jerose of Agrilab Technologies and work-study students.

The composting and thermal energy system began initial compost mixture and operations testing in the summer of 2013. The first full loading of the system occurred in the autumn of 2013. Data will be collected on a range of parameters, including optimal aeration timing and speed, compost recipes (mixtures), moisture content, bulk density, carbon/nitrogen ratios, and the economics of the various handling practices. This is also part of a comprehensive life-cycle analysis under long-term SARE research trials tracking carbon, nutrient, energy, and water dynamics of the farm operation and their economic implications.

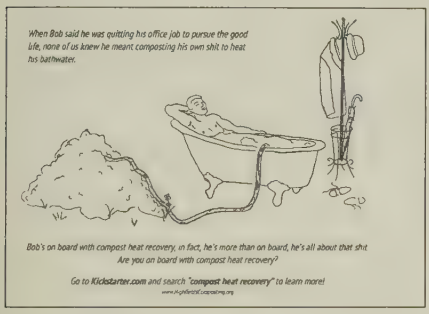
Highfields Center for Composting, a research partner of both CompostPower.org and Agrilab Technologies, is building more research infrastructure at its commercial-scale composting facility in Hardwick, Vermont, including heat-recovery systems.

Highfields got heavily involved in compost-heat-recovery research after its leading compost scientist, James McSweeney, attended a Compost Power workshop that I taught through Yestermorrow Design/Build School in 2009.

The upcoming research project has parallel but complementary approaches to the UVM research. Goals include optimizing the Jean Pain method from a feedstock and heat-exchange perspective, as well as defining

James McSweeney, compost scientist and compost-heat research project manager at Highfields Center for Composting HIGHFIELDS CENTER FOR COMPOSTING

Highfields runs compost-collection programs and is helping to refine and promote composting best practices. COMPOSTPOWER.ORG


When Bob said he was quitting his office job to pursue the good life, none of us knew he meant composting his own shit to heat his bathwater.
Bob's on board with compost heat recovery, in fact, he's more than on board, he's all about that shit
Are you on board with compost heat recovery?
Go to Kickstarter.com and search "compost heat recovery" to learn more!

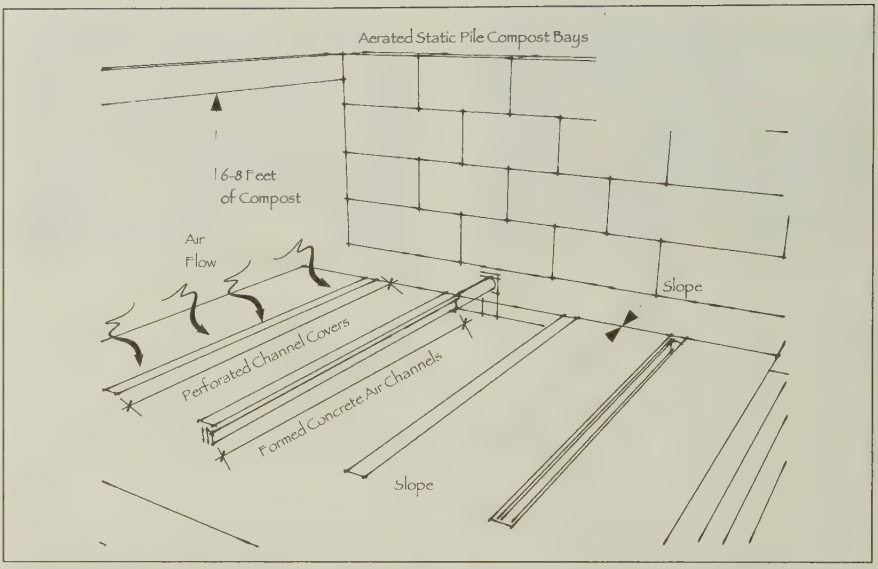
The compost-heated hot tub cartoon used in Highfields' Kickstarter campaign HIGHFIELDS CENTER FOR COMPOSTING

and refining active negative aeration as a method to capture heat and CO_2 from compost with the Isobar system and other approaches.

One creative application of the heat captured from compost will be to keep the vermicomposting room operating through the winter by running compost-recovered heat through radiant floor heating zones. Under the leadership of Executive Director Tom Gilbert with James McSweeney's tireless help, Highfields recently raised $40,000 in donations via a Kickstarter campaign to fund this and other research.

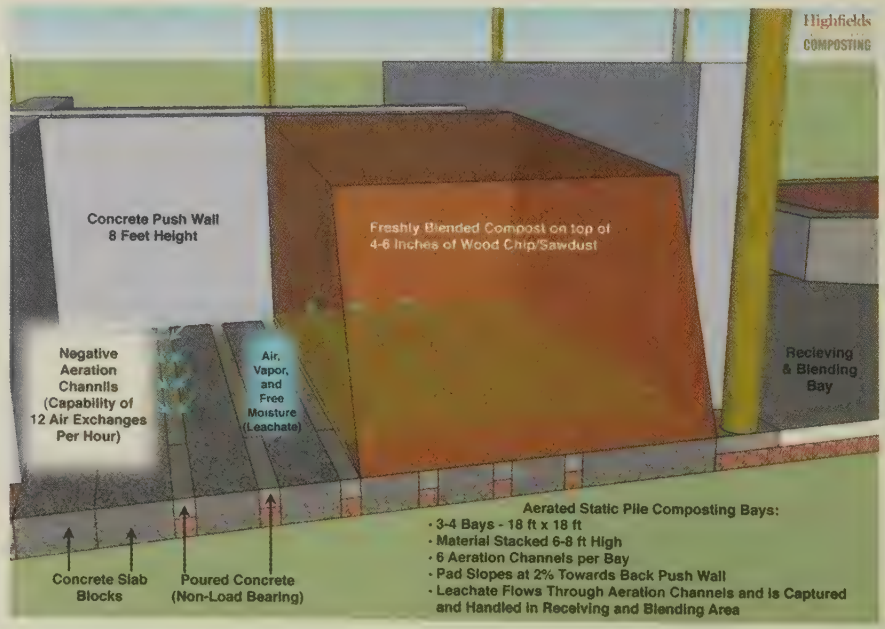
Tom Gilbert, former executive director of Highfields Center for Composting HIGHFIELDS CENTER FOR COMPOSTING

The next phase of active public and private engagement of this research began in late November 2013 with a weekend workshop. Supporters and partners of the research visited existing compost-

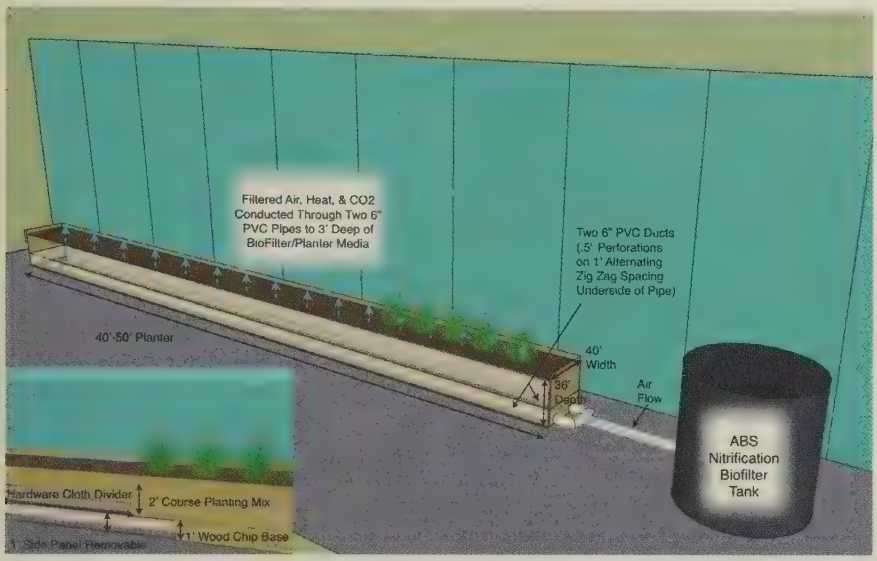


Conceptual drawing for the aerated static pile compost production bins at Highfields Center for Composting. This infrastructure will be used to test and demonstrate compost-heat-recovery methods and feedstocks, including integration into a mobile containerized Isobar system from Agrilab Technologies.

HIGHFIELDS CENTER FOR COMPOSTING


Highfields COMPOSTING
Concrete Push Wall 8 Feet Height
Freshly Blended Compost on top of 4-6 Inches of Wood Chip/Sawdust
Negative Aeration Channlls (Capability of 12 Air Exchanges Per Hour)
Air, Vapor, and Free Moisture (Leachate)
Recieving & Blending Bay
Aerated Static Pile Composting Bays:
• 3-4 Bays - 18 ft x 18 ft
• Material Stacked 6-8 ft High
• 6 Aeration Channels per Bay
• Pad Slopes at 2% Towards Back Push Wall
• Leachate Flows Through Aeration Channels and is Captured and Handled in Receiving and Blending Area
Concrete Slab Blocks
Poured Concrete (Non-Load Bearing)

Highfields' conceptual drawings of a compost-heat-exchange system



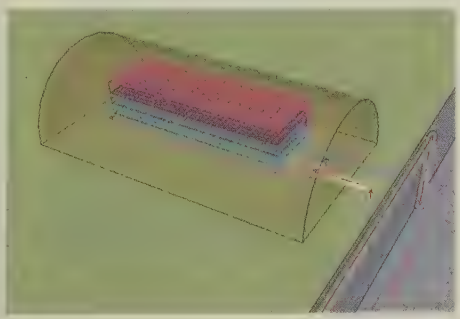
Highfields' compost vapor biofilter draining HIGHFIELDS CENTER FOR COMPOSTING

heat-recovery sites including Conan Eaton's farm, and built a modified Jean Pain system to heat the vermicomposting room. I led the Jean Pain workshop, and Agrilab consulted with Highfields on the design of this and other compost-heat-recovery tests.

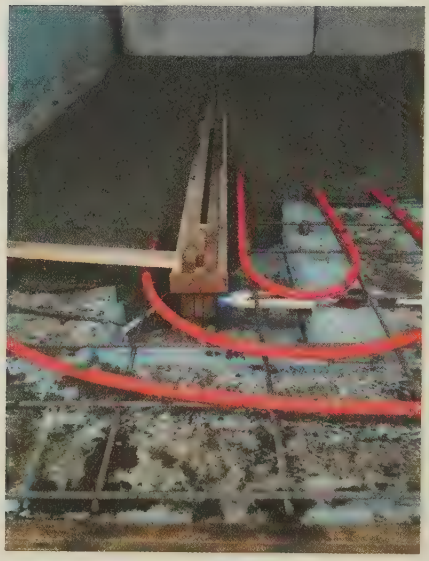
Part of the research project includes using active negative aeration of compost in specially constructed bays, enabling hot steamy air to be pulled out of the compost and run through various air-to-air, air-to-water, and air-to-soil heat-exchange and biofilter systems.

During a recent workshop that was open to the public and attended by a few dozen people, we built a modified Jean Pain–style system to provide hot water for a radiant floor heating system in vermicomposting bins.

We approached the design differently, using a long narrow windrow form instead of a circular mound. We also handled



Compost power system drawing
HIGHFIELDS CENTER FOR COMPOSTING



Construction of radiant-slab heating zones in the Highfields vermicomposting room HIGHFIELDS CENTER FOR COMPOSTING

Highfields compost power heat-exchange module, complete COMPOSTPOWER.ORG

the hydronic heat exchange in a new way, creating four separate heat-exchange zones, or layers, which were united by a manifold as the system was built. This enabled much faster construction and deconstruction.

About 150 feet of 0.75-inch poly tubing was affixed with zip ties to each of the four cattle panels. After the vertical-aeration tubes were set in place, we used a loader to dump a 2-foot-thick layer of a 60/40 blend of bark mulch (maple and red birch) and horse bedding; we then spread this with rakes as we soaked the material. We used approximately 70 cubic yards of material in total.

Some people worked on the heat-exchange modules and building the mound; others dug and insulated the supply/return water lines between the vermicomposting room and the mound.

As we laid into place the layers of compost feedstock and heat-

Highfields compost power project, phase one COMPOSTPOWER.ORG

LEFT & RIGHT: *Highfields insulated water lines in a trench* COMPOSTPOWER.ORG

Steaming compost is dumped on the heat-exchange module at Highfields.
COMPOSTPOWER.ORG

The manifold that combines each of the four heat-exchange modules into one supply and one return pipe.
COMPOSTPOWER.ORG

exchange modules, we combined the latter in a manifold, which is basically just a series of T-connectors that join the supply/return pipes into one line going into the trench.

Inside the building, the water lines were plumbed to a 400-gallon uninsulated water tank that will provide passive heat to the room. A separate water line and pump will be used to move water from the tank to the radiant heating loops in the floor.

Chapter 5
Project Planning Guide for a Small-Scale Jean Pain System

This chapter includes detailed design parameters and step-by-step instructions for building a small-scale modified Jean Pain–style system for winter greenhouse heating. This report was created by Agrilab Technologies and Compost Power for a farm in Vermont, aiming to heat a winter greenhouse in 2013.

You can adapt the detailed instructions and general approaches here to your own projects as needed, without professional help, as long as you pay careful attention to details and apply the knowledge of the composting variables described in the rest of this book.

System Parameters and Goals

1. Produce a heating output of 10,000 Btu/hr via hot-water production in the temperature range of 110 to 130°F, continuously from late October to the end of April.

2. Supply an in-greenhouse water storage tank with enough 110 to 130°F water to supply the radiant floor heating system in four to six greenhouse seedbeds that are 40 feet in length with four to six separate radiant zones (one for each seedbed/row). Radiant heating system design and installation are outside the scope of this report but can be kept simple and low-cost by installing a manifold on the storage tank and using a simple circulation pump such as a Taco 0.25-horsepower pump to move hot water from the tank into the radiant heating zones.

3. Locate the compost-powered heating system directly next to the greenhouse as discussed during the site visit to minimize the length of below-grade insulated supply/return pipe runs.

Recommended System Design and System Parameters

1. Forty cubic yards of the following recipe options for the feedstock:

a. Double-ground brushwood using sources identified by Compost Power, with up to 30 percent of the total being sawdust and up to 10 percent fresh manure blended in (if available). Adding some fresh sawdust and/or manure to the shredded brushwood will increase the temperature profile of the system by 10 to 20°F, especially during the first four months of operation, and enhance the value of the finished compost. Sawdust and manure are not necessary, however, given the ideal texture and makeup of the available material.

b. Absolute avoidance of all rot-resistant wood species such as hemlock, cedar, black locust, and Douglas fir.

c. The feedstock must be relatively fresh or from a dry-storage facility.

d. Large amounts of water will be required to thoroughly soak the feedstock as the system is built.

2. PEX or polyethylene tubing for the in-compost heat-exchange loops and below-grade insulated supply/return lines:

a. Nine hundred feet of 1-inch-diameter tubing, preferably purchased in 300-foot sections. Using 100 PSI polyethylene tubing is adequate and much less expensive ($100 for a 300-foot roll) than 160/200 PSI tubing ($200 for a 300-foot roll).

b. Couplings, connectors, and ring clamps for the tubing. The number of couplings depends on the length of each section of tubing.

c. Pipe insulation and impermeable 4-inch conduit for the below-grade supply/return lines between the compost power system and the greenhouse hot-water storage tank: two 15-foot sections of conduit and 30 feet of pipe insulation to go over the poly tubing runs (with each run then inserted into the conduit to prevent groundwater from getting near the pipes).

3. In-compost heat exchange:

a. One 900-foot loop in the compost, over seven layers; each layer of concentric rings of pipe laid out in approximately a 10-foot-diameter circle, each ring spaced approximately 6 inches from the other rings, approximately 130 to 150 feet of tubing per layer.

Evergreen State College's heat-exchange coil. COMPOSTPOWER.ORG

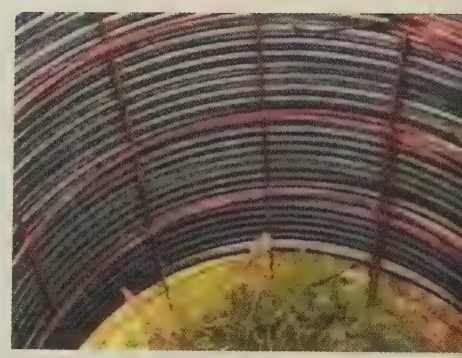
b. **Alternative heat-exchange system:** Build three pre-assembled 6-foot-tall columns of cylindrical-shaped fencing material each wrapped with 300 feet of polyethylene tubing with supply/return lines oriented at the top of each column.

   i. Start with 20 feet of 6-foot-tall hardware cloth or medium-grade chicken wire.

   ii. Create three 6.5-foot-long sections, and form them in a cylindrical column.

   iii. Starting at the top of each column, wrap the polyethylene tubing around the outside of the column, affixing it with zip ties, spacing each ring of tubing 1.5 inches from the layer above it.

   iv. Once the coiled column is wrapped to the top, create four bottom-to-top loops through the inside of the column and back up and around the outside, spaced equidistant from each other. Save 48 feet of tubing for these last four top-to-bottom loops, with the last 6 feet of tubing returning up through the center terminating near the beginning of the section of tubing.



LEFT & RIGHT: *A column-style compost-heat-exchange module* COMPOSTPOWER.ORG

Evergreen State College's heat-exchange coil COMPOSTPOWER.ORG

v. This method of heat-exchange column arrays enables faster construction and deconstruction than does the alternative of gradually laying out poly tubing across several layers of compost.

4. **Side wall structure/insulation/moisture retention:** We recommend using a stacked ring of hay bales around the compost power system to provide side wall structure and insulation/moisture retention value.

a. A system this size (a 12-foot-diameter compost power mound) would require 15 hay bales per layer, with three to five layers if that many bales are available. If you don't use hay bales, you can use hands and feet to compress and form the outer 12 inches of the compost mound on each layer to achieve side walls as close to vertical as possible.

b. If you don't use bales, keep the heat-exchange tubing in each layer at least 18 inches from the outer edge of the compost. With bales serving as insulating side walls, the heat-exchange tubing can be distributed closer to the edge of the compost (10 inches from the edge).

c. Without bales, you can use other means of achieving vertical side walls and a consistent inner column of heat-generating compost. One is to carefully pack down the outermost region of the mound as you build it. Another involves wrapping the material in chicken-wire or hardware cloth fencing material in 3-foot or taller sections while you work.

The side wall of a noncontained compost power project is compacted, while the outer ring of the top material is also packed down. COMPOSTPOWER.ORG

5. **Circulator pumps:** A ⅛-horsepower circulator pump (Taco is a common and reliable brand) is sufficient to move water from the storage tank through the compost heat-exchange loop. The rate of circulation should be kept between 1 gallon per minute (if you're circulating 45°F water into the compost heat-exchange loops) and up to 3 gallons per minute (if the "cold"-water return is above 95°F), to avoid excess stress on the microbes in the compost.

6. **Monitoring equipment options:**
   a. You can use a temperature sensor/thermometer (thermocouple) on each of the supply/return pipes between the compost system and the water tank to track temperature and heat exchange as long as you know the circulation flow rate.
   b. We recommend monitoring the temperature of soils above radiant heating loops in the seedbeds; this can be done with small, affordable temperature probes.
   c. Compost-probe thermometers such as ReoTemp can also be used, and come in various lengths up to 6 feet. But you must take extreme care when inserting a probe into the compost to avoid puncturing a heat-exchange pipe.

7. **Recommended data-logger options:**
   a. If you can establish a reliable ethernet/Internet connection and you're looking for robust remote data monitoring, we suggest using a Web Energy Logger. (You can find prices at www.welserver.com.) The nice thing about the WEL is that you can gang several sensors together on one logger (up to 50). This is by far the cheapest way we know of to measure several to many temperature points with web-based logging. The two weaknesses of the WEL are that it needs the Internet to work (when the net goes down, you'll get a gap in the data), and that if the sensor bus shorts out anywhere you lose all the data until you fix it. We've gotten pretty good at wiring these systems in ways that are waterproof and allow for quick troubleshooting, which addresses the second issue, and can offer our services in configuration of the data logger if needed.
   b. For a non-Internet approach, we recommend HOBO four-channel /data-loggers/U12-data-loggers).

i. It looks like you can now get a U12—which we recommend—for $113 (nonweatherproof) or $226. The sensors are somewhat expensive, though, so costs add up quickly; you'd need 20-foot sensors at $44 each or 50-foot sensors at $50 each.

c. When it comes to sensor placement, we recommend embedding three sensors in each seedbed/row of the greenhouse above each radiant heating zone along with a sensor on the main supply/return pipe from the compost-heating system, and at least one sensor near each heat-exchange zone inside the compost.

8. Recommended design specifications and elements:

a. **One 40-cubic-yard round system** approximately 12 feet in diameter at the base, 8 to 12 feet in diameter at the top depending on construction method, and 7 to 8 feet tall.

b. **Aeration tubing:** 100 feet of **4-inch corrugated/perforated drainage pipe** should be laid out in concentric circles on the ground in a 10-foot-diameter circle with one end terminating in the center, the other beyond the footprint of the mound so outside air can enter. In extreme cold climates it is advisable to connect the air-in side of the aeration tube to an "earth tube," which pulls air through a long pipe buried 4 feet belowground, so that the air coming into the bottom of the compost is prewarmed to 45°F by the earth's ambient temperature.

c. **Structural side walls/insulation:** Use hay or straw bales if available. Vertical side walls enable larger amounts of heat exchange to happen higher in the material and create a consistent column of material to enhance the chimney effect of passive aeration. If bales are not available, you can use sections of fencing material held in place with posts around the perimeter to create a containing side wall. It's also possible to build a near-vertical side wall by packing down the outside edge of the compost mound as you build it, but this will still result in the upper regions of the mound becoming narrower than the bottom. This may reduce heat-exchange potential in the upper region of the mound.

d. **Maximum height** of a Jean Pain–style system is 18 feet, to avoid risk of spontaneous combustion from too much chimney effect. This design has a height of 7 to 8 feet.

h. **Heat-exchange zones in a compost power mound:**

i. A single 900-foot-long compost heat-exchange loop of 1-inch-diameter polyethylene tubing spread across seven layers. Lay the first layer of pipe after you spread 18 to 20 inches of feedstock on top of the aeration tubing; spread 10 inches of feedstock in between each subsequent layer of heat-exchange pipe.

ii. Each heat-exchange layer would consist of this approximate configuration, pending revisions upon construction:

1. Starting with the first layer of pipe along the outside edge of the compost, unroll the pipe and hold it down in place (using cinder blocks or wood blocks temporarily) while you unroll the pipe and coil it in toward the center; the inner ring of coil should be laid in approximately a 20-inch-diameter circle, taking care not to kink the pipe.
2. Set the roll of pipe aside, and cover that layer of heat-exchange tubing with 10 inches of feedstock that is thoroughly soaked with water.
3. Repeat steps 1 and 2 until you have seven layers of heat-exchange tubing in place or until your tubing is used up.
4. Connect the end of the final section of heat-exchange pipe to the hot-water-return pipe that goes down into the center of the mound and into the insulated pipe/trench.
5. Then cover the top layer of heat-exchange pipe with a 20- to 24-inch layer of feedstock.

i. **Alternative heat-exchange (HE) column array installation:**

i. After you've thoroughly soaked 18 to 20 inches of compost feedstock and spread it on top of the aeration tubing, place the three HE columns around the center of the mound, spaced 8 inches equidistant from one another.

ii. Run the cold-water-supply and hot-water-return lines from the insulated trench that come up through the center of the floor of the mound in between the three HE columns.

iii. Connect the cold-water-supply line to the cold-water-supply line of the first HE column.

iv. Connect the hot-water line-out from the first HE column to the cold-water line-in to the second HE column.

v. Connect the hot-water line-out of the second HE column to the cold-water line-in of the third HE column.

vi. Connect the hot-water line-out of the third HE column to the hot-water-return line that goes back into the insulated trench to the point of use.

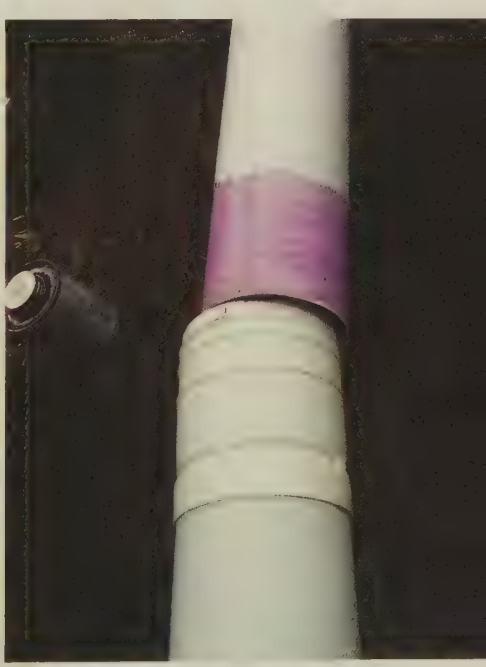
Step-by-Step Construction Directions

See the images showing the stages of each approach and step.

1. Dig a 3-foot-deep and 10- to 16-inch-wide trench from the location of the water storage tank in the greenhouse to the center of where the compost power mound will be located.

2. Install pipe insulation on a 15-foot length of poly tubing, and insert that into a 15-foot section of nonpermeable flexible 4-inch corrugated plastic conduit pipe. This will be the hot-water-return pipe.

Below-grade trench at Evergreen State College. COMPOSTPOWER.ORG



Conduit for below-grade pipes COMPOSTPOWER.ORG

3. Lay that conduit/pipe in the trench with 10 feet of poly tubing extending from the end of the conduit up out of the compost end of the trench. Use duct tape to seal the end of the conduit around the poly tubing to prevent any water from draining down into the conduit.

4. Install pipe insulation on the first 15 feet of one of the 300-foot rolls of tubing, then insert this into the other 15-foot section of conduit. This is the cold-water-supply pipe.

5. Lay the end of the insulated cold-water-return pipe into the trench extending to where the center of the compost mound will be. Set the remainder of the 300-foot roll of tubing aside. If you're using the alternative HE column approach, repeat step 4, lay another section of insulated pipe/conduit in the trench next to the hot-water-return line, and zip-tie a 10-foot section of this pipe to the stake in the center of the mound. Mark this pipe with a COLD WATER SUPPLY marker. Use duct tape to seal the end of the conduit in the trench around the extending poly tubing to prevent any groundwater from entering the conduit.

6. Measure and mark the footprint of the outer perimeter of the mound in a 12-foot-diameter circle, ensuring that the supply/return pipes to the greenhouse terminate near the center of the perimeter of the site where you'll build the mound.

7. Run any wires for in-mound sensors next to the pipe conduits and into the center of the mound site, laying the compost end of any sensor wires to the side temporarily (later to be embedded in the compost).

8. Cover the insulated conduit/pipe/wires with dirt, filling the trench.

9. Insert a 10-foot stake into the center of the mound site, where both pipes come out of the trench. Use tape or zip ties to affix the 10 feet of remaining pipes of the hot-water return and cold-water supply, so that this pipe will extend up into what will be the top/center of the finished compost mound.

Aeration tubing at the Evergreen State College project COMPOSTPOWER.ORG

10. Lay out the perforated aeration tubing in well-spaced concentric circles on the ground, with one end terminating in the center, the other slightly outside the mound perimeter.

11. If you're using hay-bale insulating side walls, lay out the first course around the perimeter, leaving a 12-foot-diameter circle on the inside edges of the bales. If you're using wire fencing containment walls, lay out the first 3-foot-tall section of fence/posts.

Insulating hay-bale wall for the compost power project at Three Crows Farm in Jeffersonville, Vermont COMPOSTPOWER.ORG

12. Cover the perforated tubing with an 18- to 20-inch layer of compost feedstock that's been thoroughly soaked; spread evenly. If you're not using hay bales or another side wall structure, pack down the outer 12 inches of the material with your feet.

Evergreen State College second layer, complete COMPOSTPOWER ORG

Evergreen State College heat-exchange coil COMPOSTPOWER.ORG

13. Lay out the first HE layer of poly tubing in place (using the remainder of the cold-water-supply line that comes from the insulated trench) on top of the first layer of feedstock.

a. Starting with the outside ring (keeping the pipe 10 to 18 inches from the edge of the compost feedstock), lay out concentric rings spaced 6 inches apart until the inner ring is in place.

b. As you unroll the pipe and lay it on the feedstock, coiling it in toward the center, hold it in place temporarily using cinder blocks or wood blocks. Lay the inner ring of coil in approximately a 20-inch-diameter circle, taking care not to kink the pipe.

c. Set the remainder of the roll of pipe aside.

d. Cover that layer of heat-exchange tubing with 10 inches of feedstock that is thoroughly soaked with water; pack down the outer 12 inches and make sure you have a consistently level layer. Use the cinder blocks that are temporarily holding the pipe in place as a gauge to determine depth.

e. Remove the blocks. Use feedstock to fill in the gaps this leaves.

f. Repeat steps a through e until you have seven layers of heat-exchange tubing in place and have used up all 900 feet of the heat-exchange tubing.

g. Connect the end of the final section of heat-exchange pipe to the hot-water-return pipe that goes down into the center of the mound and into the insulated pipe/trench.

h. Cover the top layer of heat-exchange pipe with a 20- to 24-inch layer of feedstock and then a layer of loosely packed wet hay or straw to retain moisture.

14. If you're using alternative heat-exchange columns:

a. Before you lay out the perforated tubing and the first 20-inch layer of hot mix, run a section of insulated polyethylene tubing from the greenhouse into the trench with a 10-foot section tied to the center stake next to the hot-water-return pipe. These two sections of pipe will be connected to the plumbed-in-series heat-exchange columns as a final step of construction.

b. On top of the first 20-inch layer of hot mix, place the three heat-exchange columns in the center of the mound, spaced 15 inches apart.

c. Plumb the supply and return lines of two of the columns into the cold-water-supply line previously affixed to the center stake, with the hot-water

Final plumbing at the top of a compost power mound, connecting the hot water from the mound to the hot-water supply line that goes back down through the center of the mound, then into an insulated trench to the point of use. COMPOSTPOWER.ORG

line from the second column tied into the cold-water-supply line of the third column.

d. Plumb the hot-water-output line from the third heat-exchange column to the hot-water-supply line affixed to the center stake. This will bring hot water back through the center of the mound into the insulated below-grade trench to the greenhouse.

e. Cover the columns in thoroughly soaked feedstock, gently packing the material down to ensure the columns are filled and surrounded by the feedstock. Do not use machinery to overly pack the material.

f. Once the feedstock is near the top of the heat-exchange columns, cover it with an additional layer of at least 20 inches of feedstock material. Then cover the top with a thick layer of loose-packed wet hay or straw (to retain moisture).

g. To remove the HE columns in the future, simply rake off the top layer of compost, disconnect all the pipes from each HE column, and attach a chain or cable to drag each HE column out of the material.

15. If you didn't use hay bales as insulating structural sidewalls, we recommend covering the side walls with a 12-inch-thick layer of loose-packed wet hay or more wood chips, as an insulating moisture-retention blanket.

Evergreen State College's compost power project, complete COMPOSTPOWER.ORG

16. The compost power mound is now complete. What remains is to install the water storage tank, the circulation pump, the data logger and/or thermocouples (if applicable), and the radiant heating system that will pull hot water from the tank to the radiant heating zones.

Plumbing and Operational Overview

1. Mount circulator pump(s) to the cold-water supply to the compost on the lower end of the tank.

2. Attach the cold-water supply to a bunghole in the low side of the tank.

3. Mount the data logger and/or thermocouples on supply/return pipes, if applicable, near the tank. Affix the data-logger sensor wires, et cetera.

4. Insert a fill/bleed valve on the hot-water-supply pipe that will later be attached to the high side of the tank.

5. Fill the system with water or a glycol solution, ensuring that the fill/bleed valve allows all air to be pushed out of the system as the hot-water supply is connected to the top of the tank.

6. During the first two weeks after system is built, monitor the temperature readouts. Compost material temperature should be between 130 and 150°F within that time. Once you've achieved temperatures in that range, activate circulation pump(s) from the compost heating loop into the tank, at a flow rate of approximately 1 gallon per minute.

7. Monitor the temperature of sensors/thermometers daily during the first two weeks of active circulation. Once the compost temperatures are above 130°F, you should be able to maintain a circulation rate between 1 and 2 gallons per minute if the cold-water line into the compost is above 70°F. If the mound temperature drops suddenly at any time (which could be due to the radiant heating system drawing too much heat out of the tank and thereby sending too much cold water into the compost at too great a circulation rate), reduce the circulation of the radiant heating side of the system until temperature stabilizes in the range of 110 to 140°F.

Operational Advice

Since the actual heating load/exchange into the greenhouse radiant loops will vary depending on environmental factors and unknowns relative to thermal retention, you'll need to monitor and perhaps adjust the flow rate through both sides of the system. You'll also have to monitor the temperatures of the water, the seedbeds, and the compost mass.

If temperature of the hot-water-output water line is within 5°F of the peak temperature readout from sensors or probes inside the compost, that means you can pull more heat out of the compost, so it's advisable to increase circulation through the mound by 10 percent. If temperature of the compost mass or the hot-water supply to the radiant system at any time shows a downward trend, reduce the flow rate of both sides of the system by 20 percent per day until the output temperature stabilizes.

To determine circulation flow rate for a pump that does not have predetermined circulation speeds, you may need to use a voltage meter on the pump. Refer to the operator's manual of your circulation pump for this

method of determining flow rate. You can adjust circulation by partially closing the valve on the cold-water-supply line, restricting flow. A flow meter can also be installed on the water line to track the circulation rate.

The compost microbial ecology is averse to severe changes in flow rates or dramatic intermittency of circulation; either of these can shock the microbes, causing a temporary stalling of their culture. If at any time you notice severe temperature drops in the compost mass or hot-water output, we recommend stopping circulation for 48 hours and then restarting it at a lower flow rate, gradually increasing this flow until the output temperature stabilizes.

If the compost mass for some reason dries out, the microbes will go into hibernation and temperatures will drop. If this happens, place a sprinkler on top of the mound and let a slow trickle of sprinkler water saturate the mound for four to six hours. If you're doing this in cold weather, it's best to use warm water.

Chapter 6

Project Planning Guide for a Large-Scale Modified Jean Pain System

This customized feasibility study and design report was created by Compost Power and Agrilab for a customer interested in heating a log spalting operation through the Vermont winter. This design is theoretical and has not been tested but shows a method of "going large" with a modified Jean Pain–style system that could produce up to 60,000 Btu/hr for 6 to 12 months.

The main obstacles to this approach are the size and volume of material required, and the increased complexity of plumbing and of the annual rebuild cycle.

System Parameters and Goals

1. To create a heating output of 60,000 Btu/hr continuously from mid-October to the end of April.

2. To supply radiant heating under the spalting operations, with six separate radiant zones with a radiant-slab size of 30 by 60 feet. The radiant heating system supplier recommends 60,000 Btus to keep the spalting mass above 65°F through the winter. This Btu goal is an estimate; due to the innovative application, your actual heating needs may be significantly higher or lower.

3. The radiant slab will consist of blue board covered with radiant heating loops and a 6-inch-deep layer of sand for thermal mass.

4. The compost-powered heating system will be located directly next to the spalting/radiant slab to minimize need for below-grade insulated pipe runs.

5. Adequate tracking and monitoring systems to measure performance, including the internal temperature of the spalting mass and the Btu capture rate from the compost-powered heating system.

Recommended System Design and System Parameters

1. **Two hundred cubic yards of the following recipe for the feedstock:**
   a. Sixty percent wood chips, preferably finely ground brushwood, with 40 percent sawdust.
   b. If mill shavings can be acquired instead of wood chips, the entire system can be made from mill shavings without sawdust.
   c. Absolute avoidance of all rot-resistant wood species such as hemlock, cedar, black locust, and Douglas fir.
   d. The feedstock must be relatively fresh or from a dry-storage facility.
   e. Large amounts of water will be required to thoroughly soak the feedstock as the system is built.

2. **PEX or polyethylene tubing for the in-compost heat-exchange loops:**
   a. Thirty-six hundred feet of 2-inch-diameter tubing, preferably purchased in 600-foot sections.
   b. Couplings, connectors, and ring clamps for the tubing (the number of couplings depends on the length of each section of tubing). We recommend using 600-foot rolls since each zone will be 600 feet, but 12 rolls of 300 feet each can also work; this would require 12 couplings plus couplings for the circulation pump for each zone.
   c. Each of the six heat-exchange (HE) zones/layers in the compost system should be 600 feet of tubing.
   d. T-connectors for constructing the manifold that unites the six compost HE zones with a main supply/return to the spalting radiant heating system. For alternative HE columns, simply connect the cold-water supply on one column to the cold-water-supply line from the insulated trench; plumb the remaining columns together in series and connect the hot-water

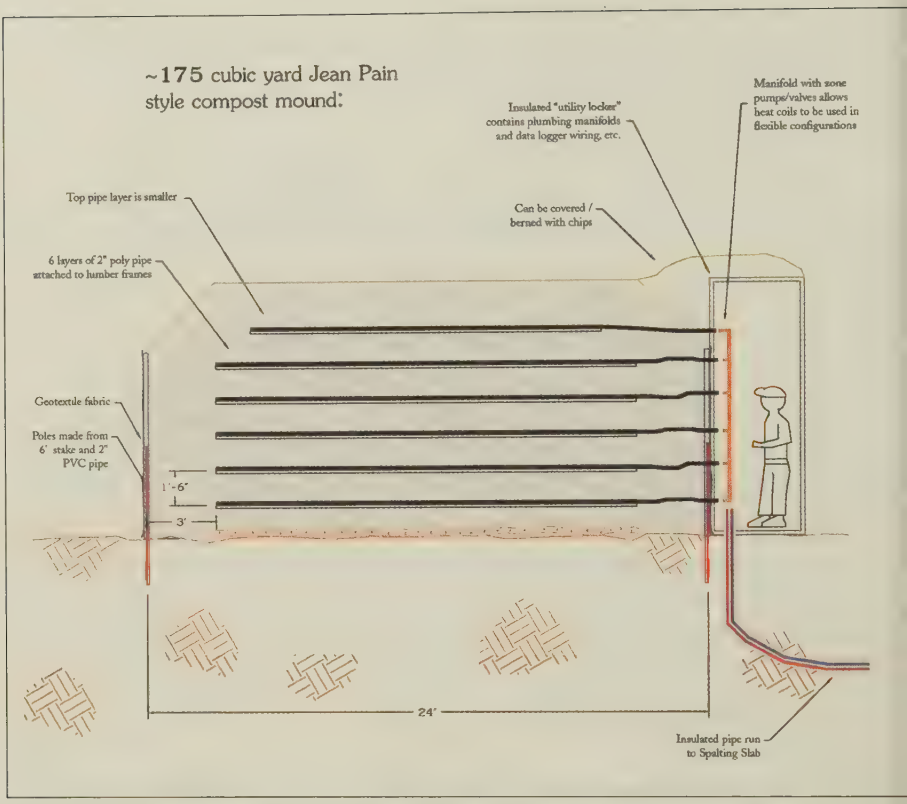
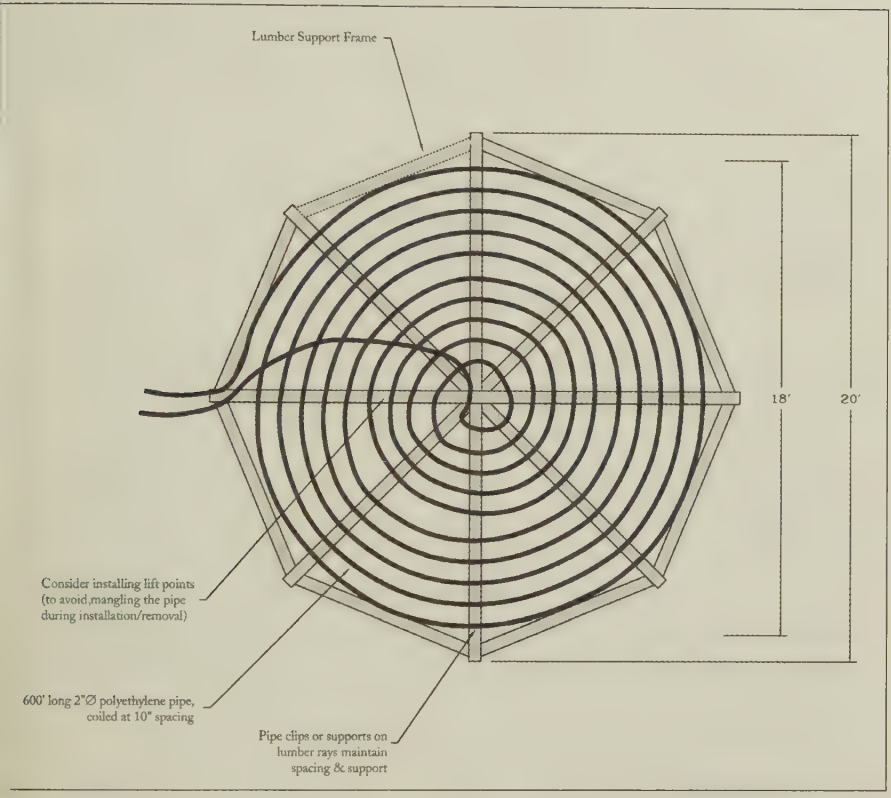

~175 cubic yard Jean Pain style compost mound:
Insulated "utility locker" contains plumbing manifolds and data logger wiring, etc.
Manifold with zone pumps/valves allows heat coils to be used in flexible configurations
Top pipe layer is smaller
Can be covered / berned with chips
6 layers of 2" poly pipe attached to lumber frames
Geotextile fabric
Poles made from 6' stake and 2" PVC pipe
1'-6"
3'
24'
Insulated pipe run to Spalting Slab

Diagram and schematic for a large-scale modified Jean Pain–style system that could theoretically provide 60,000 Btu/hr, using modular heat-exchange structures combined by a manifold. AGRILAB TECHNOLOGIES

return from the last column to the hot-water-return line in the below-grade trench.

- Construction by a competent plumbing/HVAC professional of the vertical manifold that combines the hot water from the six compost HE zones, allowing for zones to be integrated with the spalting radiant heating system in series or parallel. The manifold will need significant flexibility to allow for the supply lines from the compost to move as the composting material settles over time.
- **Heat-exchange modular structures** to facilitate easy construction, deconstruction, and reuse. See the attached schematic. Since each layer of heat-exchange tubing in the system will be an independent zone of 600


Lumber Support Frame
18'
20'
Consider installing lift points (to avoid,mangling the pipe during installation/removal)
600' long 2"Ø polyethylene pipe, coiled at 10" spacing
Pipe clips or supports on lumber rays maintain spacing & support

feet of tubing, it will be easy to manifold each zone together as the system is built.

3. **Alternative heat-exchange system:** 12 pre-assembled columns of cylindrical-shaped fencing material each wrapped with 300 feet of polyethylene tubing with supply/return lines oriented at the top of each column.
   a. Start with 80 feet of 6-foot-tall hardware cloth or medium-grade chicken wire.
   b. Create twelve 6-foot-long sections, and form them in a cylindrical column. Starting at the top of each column, wrap the polyethylene tubing around the outside of the column, affixing with zip ties, spacing each ring of tubing 1.5 inches from the layer above it.
   c. Once the coiled column is wrapped to the bottom, create four bottom-

to-top loops with the remaining 36 feet of tubing. The last 6 feet of tubing should return up through the center, terminating near the beginning of the section of tubing.

4. **Side wall structure:** We recommend using geotextile fabric attached to steel posts to provide side wall structure. This lets you construct a nice consistent column of hot composting materials where each layer of heat-exchange pipe/structure is consistent. See the attached CAD drawings.

5. **Circulator pumps:** Each compost-heating zone could have its own circulator pump to move water from it into the corresponding radiant heating zone in the spalting pad. Or the six zones in the compost can be manifolded together to supply one main hot-water input and one main cool-water return to and from the spalting slab. Flow rates through each zone should be continuous, but we recommend between 2 and 4 gallons per minute depending on the monitored temperatures of both sides of the system. Pump sizing and selection should be determined by the supplier of the radiant heating system based on the total pipe/friction factor of the final radiant design.

6. **Monitoring equipment options:**
   a. A temperature sensor/thermometer on each of the supply/return pipes between the compost system and the spalting pad can be used to track temperature and heat exchange as long as you know the circulation flow rate.
   b. Since you will want to know the temperature of the spalting mass and various temperature points within the compost in order to optimize future projects, we highly recommend a more robust data-tracking system as outlined below.
   c. Compost-probe thermometers from ReoTemp can also be used, and come in various lengths up to 6 feet. But take extreme care inserting a probe into the compost to avoid puncturing a heat-exchange pipe.
   d. **Recommended data-logger options:**
      i. If you can establish a reliable ethernet/Internet connection, we suggest using a Web Energy Logger. (You can find prices at www.welserver.com.) The nice thing about the WEL is that you can gang together up

to 50 sensors on one logger. This is by far the cheapest way we know of to measure several to many temperature points with web-based logging. The two weaknesses of the WEL are that it needs the Internet to work (when the net goes down, you'll get a gap in the data), and if the sensor bus shorts out anywhere you lose all the data until you fix it. We've gotten pretty good at wiring these systems in ways that are waterproof and allow for quick troubleshooting, which addresses the second issue, and can offer our services in configuration of the data logger if needed.

ii. For a non-Internet approach, we recommend the HOBO four-channel data loggers (www.onsetcomp.com/products/data-loggers/U12-data-loggers).

iii. It now looks like you can get a U12, which we recommend, for $113 (nonweatherproof) or $226. The sensors are somewhat expensive, though, so costs add up quickly; you'd need 20-foot sensors at $44 each or the 50-foot sensors at $50 each.

iv. When it comes to sensor placement, we recommend embedding 3 sensors in the sand of the spalting pad above each radiant heating zone for up to 18 sensors in the spalting pad (1 sensor above the beginning of the hot side of each zone, 1 sensor in a central area of each zone, and 1 above the end of the radiant loop in each zone). You'll also want a sensor on the main supply/return pipe to the spalting heating system, and at least 1 sensor near each heat-exchange zone inside the compost, for a total of at least 26 sensors.

Recommended Design Specifications and Elements

1. **One large 200-cubic-yard round system** approximately 24 feet in diameter and 10 feet tall; see the attached drawings and schematics.

2. **Aeration tubing:** 400 feet of **4-inch corrugated/perforated drainage pipe** should be laid out in concentric circles on the ground with one end terminating in the center, the other beyond the footprint of the mound so outside air can enter.

3. **Structural side walls:** We recommend use of geotextile fabric held in place by metal stakes as shown in the CAD drawings. During

the construction process, the outer 3 feet of the feedstock should be thoroughly packed down by human feet to increase density and insulating thermal mass. The inner material should not be overly compacted. This can achieve a vertical side wall that facilitates efficient heat exchange and the chimney effect.

4. **Maximum height** of a Jean Pain–style system is 18 feet, to avoid risk of spontaneous combustion from too much chimney effect. Our design has a height of 10 feet.

5. **Heat-exchange zones in the compost power mound:**
   a. With a single large compost-heating system as described above, six in-compost heat-exchange zones are constructed on a wood-framed structure as pictured.
   b. Each heat-exchange module zone would consist of this approximate configuration, pending revisions upon construction:
      i. Three 20-foot 2x6 boards laid in a crisscross pattern.
      ii. Eight 10-foot 2x6s used to reinforce/connect each of the above.
      iii. 600 feet of 2-inch-diameter double-wall polyethylene tubing laid out in concentric circles with 10-inch spacing, affixed to lumber with zip ties, as shown; 3,600 feet total of tubing required.

6. **Insulated utility box** for pump(s), manifold, and monitoring equipment:
   a. A small insulated (blue board/plywood) box, approximately 3 or 4 feet square and 8 feet tall, with a small door for entry, is constructed to encase the vertical manifold, pump(s), and monitoring equipment.
   b. Supply/return lines to the spalting pad enter up from the floor of the insulated box.
   c. Twelve 2.5-inch-diameter line-in holes are drilled in the side of the box that will face the compost mound, to allow each of the HE zones in the compost to enter the box, tied into the manifold to be built inside the box. Holes should be drilled in pairs, with the first pair located at 24 inches above the bottom, and each subsequent pair at 18 inches above the last to align with the zones that will come from the compost.
   d. The box is held in place by zip ties attached to one of the stakes used to hold the geotextile fabric in place.

e. Power, Internet, and spalting-temperature sensor lines enter up through the floor of the insulated box.

Step-by-Step Construction Directions

1. Build the utility box.

2. Measure the footprint of the outer perimeter of the mound as shown, ensuring that the supply/return pipes to the spalting pad terminate on the edge of the mound's perimeter where the utility room/box will be located.

3. Run sensor wires and the supply/return pipes from the spalting pad underground to the location where the insulated utility box will be located.

4. Drive the outer containing stakes that will support the geotextile fabric around the perimeter, as shown.

5. Affix the fabric to the inside of the stakes with zip ties, and wrap the terminating end of the fabric securely around the last stake in the circle.

6. Set the utility box in place, affixing it to one of the geotextile stakes with zip ties; the HE zone holes should face the fabric so the supply/return pipes from each zone can be inserted through the fabric and into the utility box as the zones are laid into the system.

7. Lay out the perforated aeration tubing in concentric well-spaced circles on the ground, with one end terminating in the center, the other slightly outside the geotextile fabric perimeter.

8. Using a front-end loader, dump sufficient feedstock inside the containing wall on top of the aeration tubing while thoroughly soaking the material with water. Level out a 2-foot-thick layer of material on top of the aeration tube. One person may need to remain inside the containing wall throughout the construction process to align materials.

9. Heat-exchange module layer 1 installation: Lower in the first HE zone module on top of the first 2-foot-thick layer of feedstock.

10. If you're using separate heat-exchange modules for each layer:

a. Set the first heat-exchange module layer in place on top of the 20 inches of soaked feedstock.

b. The supply/return ends of the pipe from zone 1 are stuck through small holes in the fabric and into the utility box.

c. Affix the sensors and wires to the HE modules, running wires along with tubing through the fabric into the utility box.

d. Cover the HE module with an 18-inch layer of feedstock, soaking the material thoroughly.

e. Repeat steps a through d above for each HE module, laying 18 inches of feedstock on top of each subsequent HE module.

f. Once the final HE module is laid in place, cover it with a 3-foot-thick layer of feedstock.

g. Assemble the manifold in the utility box, and connect the HE zones from the compost.

h. Mount circulator pump(s) to the lower end of the manifold.

i. Mount the data logger to an inside wall of the box; connect the sensors.

11. If you're using alternative heat-exchange columns:

a. On top of the first 20-inch layer of hot mix, place the 12 heat-exchange columns in the center of the mound, spaced 15 inches apart from one another. If you're using alternative heat-exchange columns, there will only be one supply/return water line from the HE array into the utility box.

b. Plumb the supply/return lines of each of the HE columns together, in series, with the hot-water line from the each column tied into the cold-water-supply line of the next column.

c. Plumb the hot-water-output line from the last heat-exchange column to the hot-water-supply line affixed to the center stake. This will bring hot water back through the center of the mound into the insulated below-grade trench to the point of use.

d. Cover the columns in thoroughly soaked feedstock, gently packing down the material to ensure that the columns are filled and surrounded by the feedstock.

e. Mount circulator pump(s) to the lower end of the manifold.

f. Mount the data logger to an inside wall of the box; connect the sensors.

12. Connect all pipes except for the hot-water-supply pipe to the spalting pad.
13. Insert a fill/bleed valve on the supply pipe to the spalting pad.

14. Fill the system with glycol solution, ensuring that the fill/bleed valve allows all air to be pushed out.

Operational Overview

During the first two weeks after the system is built, monitor the temperature readouts. The compost material's temperature should be between 130 and 150°F within that time. Once you've achieved temperatures in that range, activate circulation pump(s) from the compost heating zones into the radiant heating system at a flow rate of approximately 2 gallons per minute initially.

Monitor the temperature of sensors/thermometers daily during the first two weeks of active circulation.

Since the actual heating load/exchange into the system will vary depending on environmental factors and unknowns relative to thermal retention, you'll need to experiment with the flow rate through the system and monitor the temperatures of the application side of the system, the compost mass, and the water.

If temperature of the hot-water output is within 10°F of the peak readout from sensors inside the compost, increase circulation from 2 gallons per minute to approximately 4 gallons per minute. If the temperature of the compost mass or the hot-water supply to the radiant system at any time shows a downward trend, reduce the flow rate of the system by 20 percent per day until the output temperature stabilizes.

To determine the circulation flow rate for a pump that does not have predetermined circulation speeds, you may need to use a voltage meter. Refer to the operator's manual for your circulation pump.

Compost microbial ecology is averse to severe changes in flow rates or dramatic intermittency of circulation: This may shock the microbes, causing a temporary stalling of their culture. If at any time you notice severe temperature drops in the compost mass or hot-water output, we recommend stopping circulation for 48 hours and then restarting it at a lower flow rate, gradually increasing the flow until the output temperature stabilizes.

Chapter 7
Greenhouse Application Design

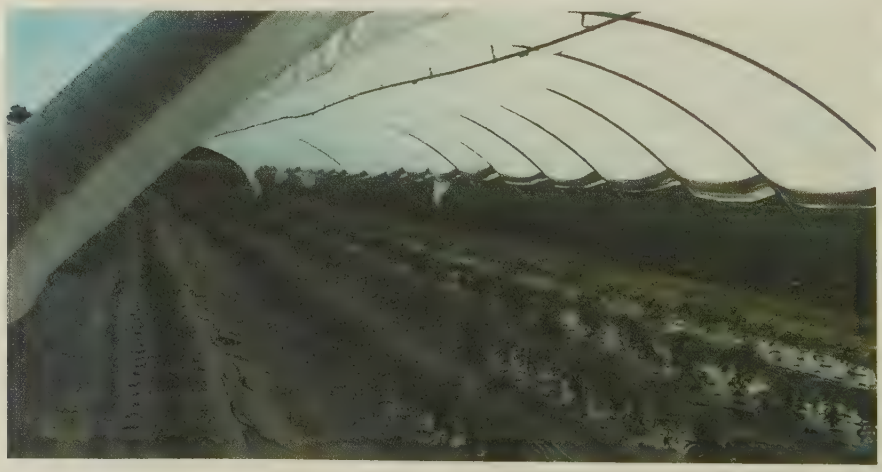
This book is not intended to provide a comprehensive analysis of best practices for greenhouse design and heating systems. However, because winter greenhouse heating is often the most compelling application for compost-heat recovery—including many of the projects I've been involved with myself—this chapter will provide a brief survey of approaches and principles to consider for best results.

Greenhouse heating is one of the best applications of compost-heat recovery for two main reasons:

1. Greenhouse operators need to invest in soil fertility and compost anyway.

2. Greenhouses need ways to bring in fresh CO_2 to feed the plants, either through expensive air-to-air exchange systems, or by bringing in fresh

A typical double-wall hoop house used to extend growing seasons in cold climates.
HIGHFIELDS CENTER FOR COMPOSTING



A soil temperature gauge reads 80°F in early winter at Jasper Hill Farm's compost-heated greenhouse. AGRILAB TECHNOLOGIES

cold air and spending energy to warm it up. Many greenhouse operators aim to have CO_2 levels between 1,000 and 3,000 ppm, compared with ambient levels of 390 ppm, which can result in up to 90 percent increases in plant growth and crop yields. Negative compost aeration that pulls CO_2-rich hot air out of compost and vents that air into greenhouses can supply all the necessary heat and CO_2 for maximum winter greenhouse productivity.

Several past/current compost-heat-recovery projects have been focused on greenhouse heating. These include the UVM Slade

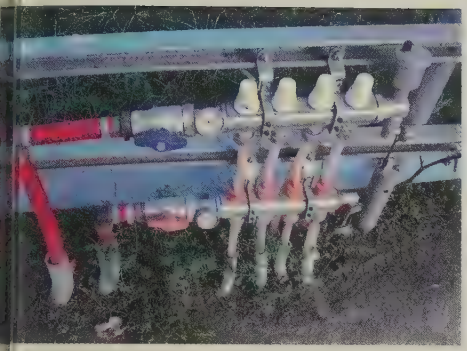
Seedbeds in Jasper Hill Farm's greenhouse—under which the 80°F warm-air exhaust from the Isobar system is vented—use compost under the soil as a biofilter, while heating the soil and adding beneficial $C0_2$.
AGRILAB TECHNOLOGIES

The compost-heated greenhouse at Jasper Hill Farm. AGRILAB TECHNOLOGIES

greenhouse, the UVM Hort Farm compost-heated greenhouse, Ben Falk's earth-coupling compost-heated greenhouse, Jasper Hill Creamery's greenhouse, Acrolab's compost-heat-recovery testing facilities in Toronto, Bruce Fulford's NAI experiments, and dozens of small-scale Compost Power Network projects such as Kingsbury Farm (all described in other chapters of this book).

The best methods of distributing compost-powered heat into the greenhouse are via radiant floor heating loops in seedbeds, or by hot CO_2-rich air pulled from compost being blown into thick layers of mature compost underneath seedbeds.

Compost-heat-recovery ductwork in the UVM Hort Farm greenhouse channels hot steamy air directly into a biofilter of mature compost under the seedbeds. AGRILAB TECHNOLOGIES



Kingsbury Farm's greenhouse has radiant heating valves for each zone
COMPOSTPOWER.ORG

Ben Falk stands between his compost power mound and his greenhouse.
BEN FALK

LEFT: *The compost-production area is on the north wall of the greenhouse at Jasper Hill Farm. This ductwork in the greenhouse is from compost aeration channels that bring steamy 140°F air to the Isobar heat exchanger and ultimately to the seedbeds.*
RIGHT: *The interior of the UVM Hort Farm compost-heated greenhouse*
AGRILAB TECHNOLOGIES

Many winterized greenhouses have several black water storage tanks placed in the north wall. Typically these tanks are used to capture solar energy in the day and store heat through the night and on cloudy days, minimizing the need for other heating sources. In compost-heated greenhouses, you can keep the water in these tanks hot at night and on

Small-Scale Compost-Heated Greenhouses

Several greenhouse operators in Vermont and New Hampshire built systems in 2013 similar to the Evergreen State College and UVM Slade greenhouse systems. These include Kinsbury Farm in Warren, Vermont, Gaylord Farm in Waitsfield, Vermont, Three Crows Farm in Jeffersonville, Vermont, and the Earle Family Farm in Conway, New Hampshire.

All of these systems will heat winter greenhouses by using compost-heat recovery to keep water tanks and radiant seedbed heating zones full of hot water. In some cases one or more storage tanks of hot water are kept in the greenhouse, with water being circulated by a small pump through the compost heat-exchange loops and back to the water tanks, and radiant floor heating loops in seedbeds circulating water from the storage tanks to keep seedbeds warm. In other projects there are no water storage tanks; the circulation from the compost loops goes directly into radiant floor heating zones in seedbeds.

When hay or straw bales are not available for insulating side walls, the outer 12 inches of the mound is compressed by human feet as it is built, à la Jean Pain. In these cases, extra care and time are taken

COMPOSTPOWER.ORG

Kingsbury Farm's compost power project with greenhouse in the background

Earle Farm compost power project, completed COMPOSTPOWER.ORG

Hot-water storage tanks at Earle Farm COMPOSTPOWER.ORG

to pack the side walls of the mound and the top outer ring of each layer of feedstock, using teamwork to keep the side walls as close to vertical as possible. This enables the higher sections of the mound to maintain a large enough diameter that significant amounts of heat-exchange tubing can be distributed there. If this care is not taken, the mounds would tend toward a conical top, getting very narrow once a height of 5 or 6 feet is reached.

Another means of maintaining vertical side walls is to use materials such as chicken wire and fence posts to contain the material. This approach is effective but often presents challenges during construction related to getting people and materials in and out of the fenced-in circular area it creates.

Radiant heating system in the greenhouse at Kingsbury Farm COMPOSTPOWER.ORG

Angus Baldwin, a young Vermont farmer, and his son make their way to building a compost power mound. ANGUS BALDWIN

My own early experiments in my front yard included many valuable failures in terms of systems not quite staying hot through the winter. We learned that Jean Pain–style systems made with regular large wood chips as the primary feedstock can provide water of 110°F and warmer in non-winter months—but these systems don't get hot enough to keep winter temperatures at bay unless they are very large.

We learned that it's perhaps not a good idea to overly compact the material even though it seems that Jean Pain put a lot of effort into packing his systems down. We learned that laying a coil of flexible perforated aeration tubing on the ground before spreading out the feedstock can create a nice passive-aeration factor.

We learned that even though a lumber mill operator sells you sawdust or wood chips that he swears are made from pine, they could be hemlock! And we learned that it's easy to put up a makeshift hot tub on your porch and keep it at 104°F by using a sump pump to move water through the compost heat-exchange loops.

But the biggest and most important lesson we learned was that inspiring people to engage in open-source research and collaboration can lead to fast-track knowledge

cloudy days by circulating through the tanks the hot water generated by a compost-heat-recovery system.

If a greenhouse has radiant floor loops in the seedbeds, you can use these storage tanks as the source of the water circulated through the loops with a separate low-power circulation pump.

Below are summaries of greenhouse design and compost-heat-recovery plans from selected projects. In winterized greenhouses, it's important to

Gaylord Farm compost power project, completed COMPOSTPOWER.ORG

building and exciting opportunity. As the Compost Power Network became more active with renewable-energy experts, engineers, and compost scientists, the concept gained a lot of steam.

In 2008 when I first started researching the topic, there were fewer than a couple dozen valid search results on Google or YouTube, mostly referencing the one Agrilab system in existence at that time, Jean Pain, or Bruce Fulford's experiments in the 1980s.

As of this writing, five years later, a search for "compost power" or "compost-heat recovery" reveals thousands of stories about various projects that people are embarking on all over the world. The open-source revolution of compost-heat hackers has begun in earnest.

have proper foundations to prevent frost from moving under the soil. Frost breaks are sometimes made with cement footings, insulated cinder blocks, or other types of earth berming around the outside of the greenhouse.

Earth coupling is an important principle that commonly places the north wall of the greenhouse at least partially belowground, using the 45 to 50°F ambient temperature of the ground to keep severe winter temperatures at bay. Another element of this concept is to place in the ground earth tubes

that bring outside air into the greenhouse. The tubes are sometimes up to 100 feet long and warm the outside winter air by the ambient temperature of the ground. Earth tubes also provide cool air in warmer months, minimizing the need and energy drain for ventilation.

Greenhouse ventilation is very important for two reasons: to prevent temperatures inside from going too high or too low, and to replace CO_2 that the plants are constantly absorbing. A greenhouse with no fresh air inlets will starve itself of CO_2 within just a couple of days, killing the plants.

Enrichment of the air with CO_2 that is pulled out of compost is a brilliant side benefit of compost-heat-recovery systems for greenhouses.

Justus Walker, an American now living at a monastery in a remote region of Siberia, is making grand plans for using compost and earth-coupling techniques and cohabiting animals in a building connected to a greenhouse to keep the greenhouse productive through the Siberian winter, which regularly has -50°F temperatures.

Here is Walker's description of his plans, along with a CAD sketch visualization:

> **First, let me give you an overview of my project. I will have a 50ft by 20ft greenhouse. Underneath the greenhouse will be a nine foot deep, twelve feet wide 30 foot long root cellar/cold-trap. Behind the greenhouse area I will have an enclosed 20 foot by 50 foot barn where I will house horses, goats and sheep. There will be another cold trap trench between the greenhouse area and the barn area, seven feet wide and four feet deep from the floor of the greenhouse on one side with the barn on the other.**

Walker plans to earth-berm the outside north, east, and west walls of the greenhouse and the other elements of his structure with dirt from excavation of the sunken foundation. The greenhouse floor will be 3 to 4 feet into the ground level. Excavation of the below-grade root cellar, the cold sink trench, drainage ditches, and the ramp to get into the greenhouse will provide massive amounts of earth-berm material. Above the barn area will be a hayloft that will provide winter insulation as well as ventilation in the summer when it's empty.

Justus Walker

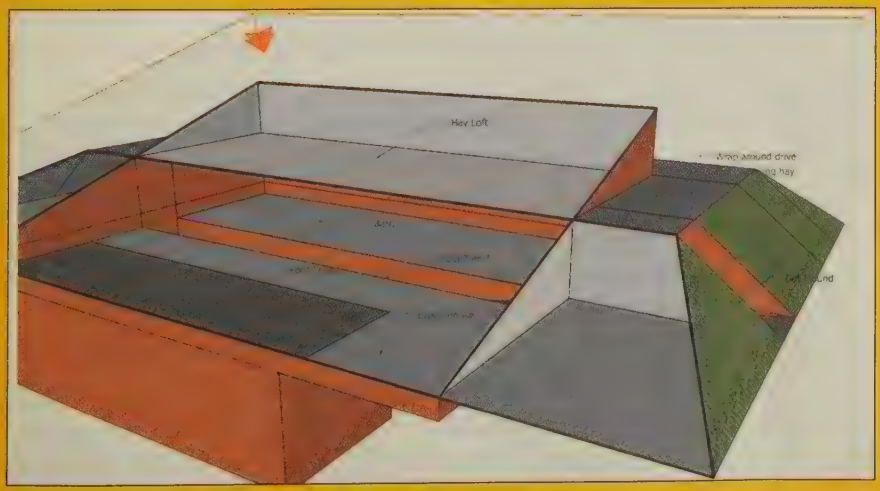
Justus Walker has been experimenting in Siberia with modified versions of the Jean Pain method with advice from Compost Power since 2009. One of his limitations is that the only available feedstock in his area is sawdust. Still, this material is available in massive and affordable quantities, so he's trying to make compost-heat recovery work with large mounds of it.

This presents an interesting challenge due to the texture of sawdust. In order for the composting process to happen, the microbes need enough air and water. When sawdust is too wet, it can become overly compacted, blocking airflow.

Walker's initial experiment was to simply test the temperatures of large wet sawdust piles through the Siberian winter. Temperature readings inside the core of the piles rarely dropped below 80°F, even after multiple weeks of -40°F in the middle of the winter.

Walker is happy to get 80 to 100°F water for radiant heating loops in the greenhouse, but Compost Power is advising him on ways to increase that temperature. It is believed that increasing the aeration of his sawdust will make the microbial culture more active and generate more heat. He is exploring ways to contain the material to create taller cylindrical systems that will have more chimney effect (aeration), and to distribute aeration tubing under the mass.

His greenhouse/heating project is quite ambitious: to keep a greenhouse productive through the Siberian winter without burning any fuel.



Justus Walker's CAD drawing of a compost/livestock-heated barn/greenhouse in Siberia JUSTUS WALKER

Since the entire structure's floor/foundation is below the frost line, the 45°F ambient temperature of the earth will provide significant winter warmth compared with the -50°F winter air. Walker is installing radiant floor heating zones in the floor of the greenhouse section of the structure, which will be supplied with hot/warm water by his compost-heat-recovery system.

He is exploring ways to connect earth tubes to the aeration tube in the bottom of his compost power system. This will supply 45°F preheated air into the bottom of the compost, instead of -50°F winter air, preventing winter air from cooling off the compost. The natural chimney effect updraft that is created by the heat at the top of the compost mound would passively aerate the compost with air preheated by the earth tube.

Walker wants to avoid any need for electricity or mechanical moving parts, so he's not planning on using active aeration to draw CO_2-rich warm air out of the bottom of the compost into the greenhouse. The animals in the structure should provide plenty of CO_2 for the plants in the greenhouse, and his air inlets for greenhouse ventilation will come from earth tubes, vastly minimizing the cooling impact of bringing in fresh air during winter months. For updates on Walker's endurance project, visit www.senttosiberia.com.

Zach Weiss, a participant in the Compost Power Network, is a professional winterized greenhouse builder specializing in ways to use earth coupling/berming to enable solar-heated winter greenhouses. Some of his projects are producing tropical fruits and vegetables through the winter in places like Montana, without fossil fuels for space heating.

His innovative ideas and practice include integrating compost-heat-recovery systems with earth tubes providing preheated aeration to the compost, which is a smart way to keep the compost from being cooled in winter months. His methods of earth coupling and super-insulated/bermed northern walls, along with advanced greenhouse film materials of high R-value, can be found on projects across the United States, including Ben Falk's greenhouse at Whole Systems Research Farm in Moretown, Vermont. For more information about Weiss's methods and projects, visit his website www.perpetualgreengardens.com.

Bruce Fulford's NAI compost-heated greenhouse was one of the most ambitious and interesting experiments in the history of greenhouses, in my opinion. Below is a detailed description from an NAI report on design principles, construction details, and the performance of this greenhouse during its four years of operation in the mid-1980s in Cape Cod, Massachusetts.

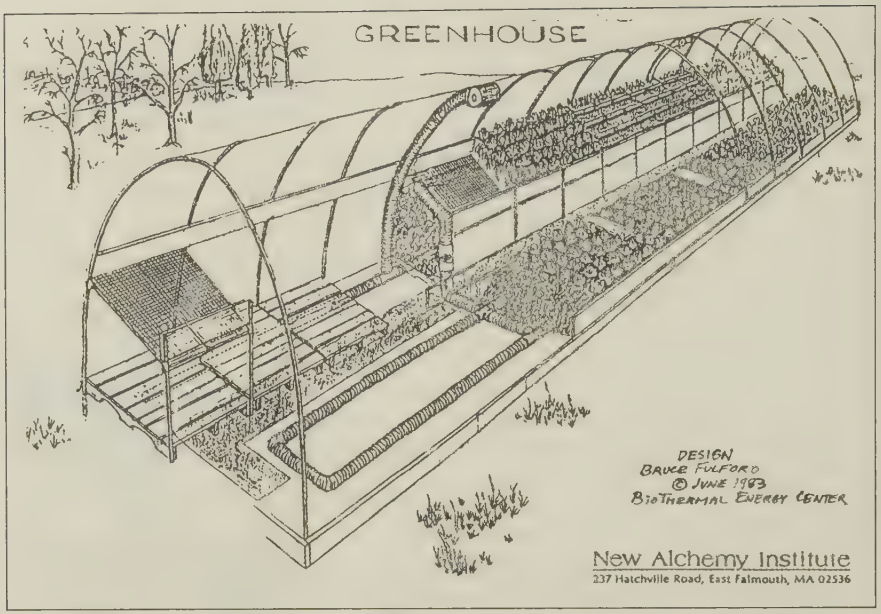
The project aimed to determine the best ways to integrate compost production into the inside of the greenhouse, to benefit from the CO_2 and heat generated by the compost while maximizing space for plants in the greenhouse.

The New Alchemy Institute's compost-heated greenhouse was operated in the mid-1980s by Bruce Fulford and others. BRUCE FULFORD

This research report summarizes more than two years' research on the design, construction and testing of an experimental composting greenhouse developed by the Biothermal Energy Center and the New Alchemy Institute in early 1983. A joint research project at the Institute's 12-acre research and education farm on Cape Cod, Massachusetts combines modem composting and horticultural practices in the same structure.

Compost is enclosed in an insulated chamber within the greenhouse. Heat and carbon dioxide liberated by bacteria during composting are used to enhance the production of greenhouse crops and eliminate fuel costs normally associated with running greenhouses, and offset costs of running this moderately-sized composting operation. The 576-square-foot test composting greenhouse produced more than 100 tons of compost and tens of thousands of seedlings in its first full year of operation.

The composting chamber along the north wall of the greenhouse was built out of a framed polyurethane-sealed, pressure-treated 2-by-4 lumber on 12-inch centers with 1-inch



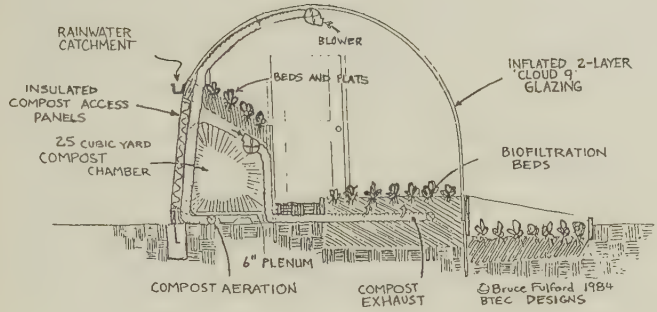
BRUCE FULFORD

ABOVE & RIGHT: *Fulford's pre-construction drawings of the NAI compost-heated greenhouse*

bench mesh stretched across them. It was angled at 30 degrees to ease handling of the compost from the outside and access to plants from the inside. The bed was supported by a north wall, constructed with 4-by-4 lumber 4 feet apart on center.

Rigid insulated panels of foil-faced 2 inch (5 cm) polyisocyanurate laminated between two layers of 0.04 inch (0.1 cm) FRP (fiberglass reinforced plastic) were fabricated to seal the 4-by-4 foot access bays. A retaining wall of 4-foot-long 2-by-8 inch boards is stacked against the inside of the 4-by-4 inch pillars as the compost is loaded, leaving a recessed cavity for the insulating panels. A gutter was hung above the compost chambers to keep ice from forming around the doors. This simple system reduces the labor involved in loading and maintaining the compost, while minimizing north-wall heat loss from the compost.

The inner (south-facing) wall was fabricated of recycled cedar 1-by-6 inch tongue and groove boards screwed onto cypress



2-by-6 inch uprights buried 18 inches (46 cm) into the ground. A layer of old FRP glazing was tacked onto the compost side of this surface. All seams and holes were sealed with silicon to prevent air leaks into the greenhouse.

The compost chamber volume is about 25 cubic yards (19 m^3), excluding airspaces above and below the compost. The roof of the compost chamber is heavy, galvanized 1 inch (2.54 cm) bench mesh supported by treated 2-by-4s, which holds a 12-inch-deep (30 cm) filter and growing bed.

The floor of the chamber is made of bench mesh supported by wooden packing pallets to allow air from the greenhouse to be circulated through the compost from an air plenum underneath the composting chamber. (Fulford/NAI)

Heat Transfer System

Heat is transferred from the compost chamber to the lower filter/bed by drawing off water vapor (steamy hot air) from the top of the compost chamber and blowing it through perforated pipe in the front growing bed. Here and in the growing bed suspended directly above the composting chamber heat is efficiently transferred as the water vapor condenses and releases the stored latent heat of evaporation to the surfaces on which it lands.

essential for effective pathogen kill through the pile. This design also ensures more complete thermophilic activity in the whole cross section of the composting chamber, allowing for a higher percentage of total heat production area, greater weed seed kill and sterilization, without turning the compost for the entire 24-day residence in the composting chamber. (Fulford/NAI)

Biological Performance of the NAI Greenhouse

Nitrogen Formation and Filtration: The compost gives off oxidized and volatilized byproducts of the carbon and nitrogen in the pile as bacteria multiply and the mass heats to more than 150 degrees F (66 C). (Gray et al. 1971)

Ammonia gas, NH_3, begins to be formed in manures almost immediately after being excreted by the animal. Urine contains urea, which is hydrolyzed by urease in the feces and then when in contact with water becomes ammonium (NH_4+), resulting in a rapid increase in pH and total ammoniacal N content. (Lauer et al. 1976)

During the first few days of thermophilic activity, rising pH coupled with high temperatures and aeration force much of the NH_3 out of the composting manure. (Poincelot 1974) Ammonia will damage plant leaf tissue in concentrations as low as 10 ppm (Thomas 1951) and must be scrubbed from the exhaust stream before it enters the greenhouse atmosphere.

A number of experimental composting greenhouses have suffered chemical burns of leaves by NH_3 that was released directly into the greenhouse atmosphere without being filtered. The compost exhaust is drawn out of the compost chamber by blowers and forced through a porous filter that removes NH_3 and water vapor but allows CO_2 to pass through. The NH_3 is transformed to ammonium (NH_4+) when it comes in contact with the water vapor in the exhaust stream or condenses in the pipe or soil of the growing bed/filter. Some NH_4+ is absorbed by plant root hairs but most of it is mineralized to nitrite (NO_2-) and then to nitrate (NO_3-) by bacteria present in the biofilter.

The biofilter has a high carbon content, which provides a food

source for certain nitrifying bacteria. The warm temperatures and oxygen-rich environment of the biofilter also assist in rapid nitrification of NH_3 to plant-usable NO_3-. (Brady 1974)

Any soil biofilter has limitations as to how much NH_3 or other selected compounds it can process at a given time. (Selby et al. 1986) In practice, the filter we used was able to process NH_3 from regular 7.5 cubic yard (5.7 m^3) loads of manure, but during a full 25 cubic yard load (19 m^3) of fresh manure with a great deal of urine there may be too much NH_3 released for the filter to process the exhaust gases all at once.

Performance data from Japanese bodenfilters report nitrification of as much as 0.169 gram of nitrogen per kilogram of dry soil per day (1.67 x 10-4 lb N/lb dry soil/day). (Terasawa et al. 1986) The high temperatures and moist, oxygen rich environment of the biofilter approach ideal conditions for nitrifying bacteria.

The performance of the biofilter depends as much on its physical characteristics as its chemical ones. The interstices between soil particles and decomposing carbonaceous materials hold air and water when blowers are off, and permit their movement when blowers are on.

The porosity of the biofilter is enhanced by healthy populations of earthworms (Eisenia lumbricus) and manure worms (Eiseniafoetida) that create vertical tunnels through the soil as they digest carbonaceous material incorporated into or topdressed on the soil. The high carbon content of the biofilter soil seems to have buffered the heavy loading rates of NH_3 by providing colloidal surface area and increasing the action exchange capacity. Moisture levels in the biofilter also play in important role in performance.

A filter medium that is saturated with water will not permit air to flow easily through it, and the O_2 levels will be depressed as a result. Filters that are too dry will permit a great deal of airflow but will not be as efficient in gas capture, especially NH_3. The in-filter residence time and concentration of the unwanted gas also greatly affect the efficiency of removal.

The fate of various gaseous nitrogen forms in the biofilter and greenhouse atmosphere is not completely understood, and is the object of ongoing research. In order to scrub all unwanted gas particles from the exhaust, it may be necessary to make modifications to the filter, such as increasing the volume, or modifying the configuration or constituents of the filter media used to scrub NH_3 from the exhaust stream.

The biofilter can be amended with any of several organic colloidal clays to increase N retention. Vermiculite (Brady 1974) and zeolite (Johnson & Sieburth 1974, Mumpton 1981) will bind up large quantities of NH_4+ in the soil, and zeolite can actually strip gaseous NH_3 from the air as it passes through the biofilter.

Increasing the carbon content of the soil and keeping the pH below neutral will also enhance recapture and assimilation of NH_3 by the soil. It is possible that NO_3- could accumulate in the biofiltration bed where plants are grown. If soil becomes overloaded with nitrate, it can be diluted with bulking agents and new soil, removed and used in potting mixes or as a fertilizer and general soil amendment elsewhere.

During midwinter low-light conditions in many greenhouses, nitrate accumulates in many plants as they take up nitrate but lack the light to photosynthesize and reduce the nitrate to amino acids. Excessive nitrate in greenhouse lettuce is a major concern in the Netherlands, and it is possible that this biofilter configuration is unsuitable for growing certain leafy food crops in the midwinter if levels of available nitrate are high. (Brinton 1985, Vogtmann et al. 1984) (Fulford/NAI)

Soil Quality of the NAI Greenhouse

The soil audit indicates an excess of both phosphorus and potassium, although both can be present in large quantities in the soil without exerting harmful effects on most crops. There may also be a use for the high levels of P and K in assisting decomposition of organic carbon and nitrogen compounds in the biofilter.

Heavy potassium fertilization can help to offset negative effects of surplus soil nitrogen. Potassium will promote rapid root and tip development which, in turn, increase the plant's ability to take up nitrogen constantly being added via compost exhaust.

Our observations and tests by Woods End Lab (Parnes 1985) point to the benefits of maintaining high soil carbon levels which will buffer otherwise excessive soil N that is likely to be lost through denitrification. Woods End found acceptable NO_3- and NH_4+ levels in the soil, indicating that there is enough available N to support populations of carbon-decomposing, heterotrophic bacteria and the nitrifying bacteria that supply soluble N for plant growth.

However, it is clear that more tests are required to accurately determine the N banking properties of the soil bed biofiltration system. While high concentrations of NH_3 were present in the compost chamber there has been no incidence of the scorched leaves associated with NH_3 contamination. We will be investigating the nitrogen dynamics of the greenhouse and biofilter much more thoroughly in 1987. (Fulford/NAI)

Horticultural Performance of the NAI Greenhouse

The greenhouse has performed well during its first year and a half of operation. More than 50,000 seedlings have been grown in the main structure and adjacent cold frames and hot beds. We have tested several dozen vegetable, herbs, and fruiting crops, with good growth in most and outstanding production of some.

Crops were tailored to the seasonal thermal fluctuations of the greenhouse by raising lettuces and low-growing crops in winter, which stayed close to the warm soil. During spring, summer and fall, the entire volume of the structure is filled by hanging baskets, bushes, and vining crops planted in the lower bed to make maximum use of the 8-foot height of the lower growing bed.

Cucurbits such as melons and cucumbers have been trellised along the bows and purlins of the frame above the upper bed,

where the fruit hangs down for easy harvesting. Seedling germination in the hottest part of the greenhouse was excellent.

The growing bed/biofilter on top of the compost chamber proved to be ideal for starting new seedlings and getting recent transplants to root rapidly. Lettuce seeds germinated in less than 36 hours in one test. After germination and "pricking out," seedlings are moved to cooler parts of the greenhouse or the hot beds and coldframes.

We found that Buttercrunch, Black Seeded Simpson, and Green Ice lettuces did very well in the greenhouse last winter. Our best head lettuce proved to be a Dutch greenhouse variety called Karma, from Sluis and Groot. Green Scotch curled and Italian flat parsleys thrived without aphid problems. Tomatoes of the Dombito and Waltham 3112 indeterminate varieties were grown in 40 square feet of the lower growing bed/biofilter.

At first they exhibited some of the classic signs of excessive soluble soil nitrogen: lush leafy growth—until they were 3 or 4 feet (0.9–1.2 m) high, where they became stemmier and fruited with less relative leaf area.

This might point towards either excessive nitrogen or the effects of CO_2 on undergrowth closest to the source, which is undesirable in the case of tomato cultivation as it requires some extra labor in pruning. But this was accompanied by good inflorescence, fruitset and harvests not usually evident with an overabundance of soluble nitrogen in the soil. The remarkable leaf growth was accompanied by the rapid development of exceptionally thick stems. This is likely to be the product of a liberal application of steamed bone meal and greensand in that sector of the greenhouse in May 1984.

We had an outstanding crop of sweet peppers from an August planting. Many exceeded ½ lb (230 g) and had walls as thick as 5/16 inch (0.8 cm). They were grown in the upper filter/bed, seldom irrigated, and their roots dangled down into the saturated atmosphere of the compost chamber. When particularly ammonia-rich manure was loaded, these exposed root hairs would usually be killed back, but no apparent

deleterious effect on the plants was observed. Vapor from the compost condensing in the growing bed provided virtually all of the water requirements for the four month-growing season.

European cucumbers have been tested with good results in both growing beds. We have had some problems with infestations of striped cucumber beetles, which are vectors for a bacterial wilt that has decimated the crops in the first two seasons. Screened vents installed in the spring of 1986 have prevented the recurrence of that disease. (Fulford/NAI)

Chapter 8

Understanding Feedstocks for Heat Optimization and Compost Quality

Much information about compost feedstock is already woven throughout this book. This chapter is intended to summarize the variables and performance expectations of various compost feedstocks and blends in terms of compost quality and heat-recovery potential.

Steaming compost at Highfields Center for Composting COMPOSTPOWER.ORG

Woody feedstocks composted the Jean Pain way, in dense, wet, but air-permeable mounds enabling passive aeration, can stay above 120°F for up to 18 months. When manure- or food-based feedstocks are used in negative-aeration heat-recovery systems, the thermophilic cycle is usually complete after 6 to 10 weeks, with the first 4 weeks having up to twice the heat output of the last 4.

When manure- or food-based feedstocks have a high percentage of woody materials, the composting cycle can continue for several months, depending on the recipe.

The Jean Pain method of compost production and heat recovery relies on the ability of shredded woody biomass to retain water and enable passive aeration of the material without mechanical manipulation or aeration. Jean Pain spent years determining the best texture of shredded brushwood to manage the moisture and aeration variables and enable his compost systems to produce steady heat output for 12 to 18 months without any ongoing maintenance once they were built.

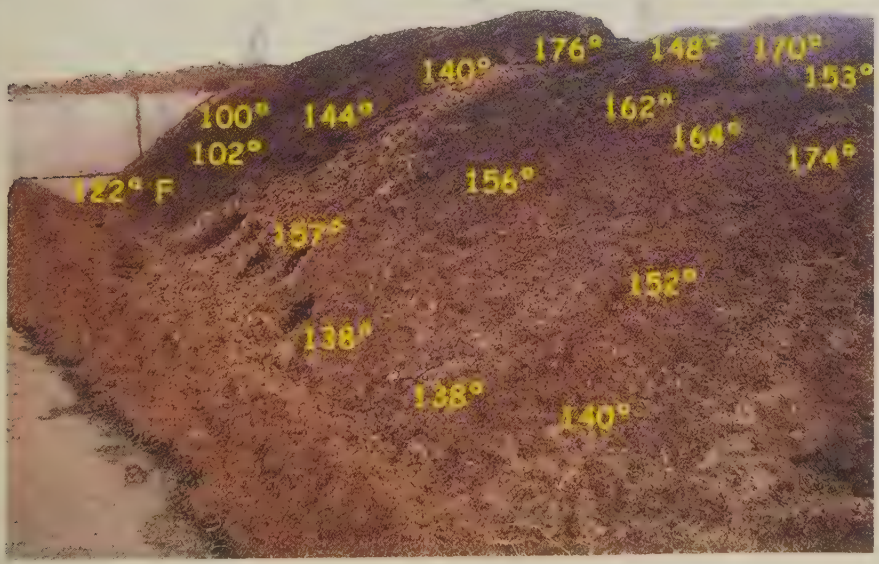
With compost made primarily from manure, agricultural waste, or food scraps, the active compost cycle usually only lasts six to eight weeks, during which time heat can be recovered.

Before we discuss feedstock variables in more detail, let's first understand the math in terms of total energy that can be captured by either method of compost-heat recovery, each relying on different feedstocks.

The energy yields per hour from modified Jean Pain systems, per ton of feedstock in a system, are not quite as high as what has been documented by the Isobar system. Small-scale Jean Pain–style systems constructed by Compost Power and Heiner Cuhls have documented a range of 500 Btu/hr per ton of material. This heat-capture rate can be sustained from the same material for a 12- to 18-month period. However, since this material takes much longer than manure-, food-scrap-, or grass-based feedstocks, much more energy can be captured over 6 to 12 months or longer from 1 ton of woody material than can be captured over a 6- to 10-week period using manure, food, or other less dense materials.

The Isobar system using manure-based feedstocks typically captures

Temperature readings at various places in a compost windrow, recorded by the Highfields Center for Composting HIGHFIELDS CENTER FOR COMPOSTING



Evergreen State College

Evergreen State in Olympia, Washington, attempted to build a compost-heat-recovery system in 2010 as a demonstration. Flaws in the design including lack of aeration and use of rot-resistant cedar as a primary feedstock created disappointing results. In 2012 Mark Allmand, the coordinator for the buildings and grounds group charged with renovating several dormitory buildings and integrating sustainability into the upgrades, started working with me on planning another attempt.

In July 2013 Evergreen brought me to the site to lead construction of a new compost power system integrated with radiant floor-heating loops in a new small dormitory building. This system was very similar to the approaches taken with the Whole Systems Design and Galt's Gulch Chile projects, using a blend of mill shavings, sawdust, and manure with perforated aeration tubing in the floor and straw bales as insulating side walls.

Evergreen State College first layer complete COMPOSTPOWER.ORG

Evergreen's feedstock was 60 percent fresh pine mill shavings, 30 percent alder sawdust, and 10 percent horse manure. The materials were thoroughly blended ahead of time and delivered the day the construction began, next to where the

1,500 Btu/hr per ton of material for the first four weeks, and 500 Btu/hr for the second four-week compost production cycle. Then the finished compost is removed and used or sold, with fresh feedstock being loaded onto the aerated compost production floor. Feedstocks consisting of food scraps and forest residues would generally have a higher heat output during that period of time than manure feedstocks.

One significant difference between the energy yields of each type of material and approach is that the wood-based systems take a lot longer to

Evergreen's temperature gauge reads 178°F. COMPOSTPOWER.ORG

system would be built. The extremely light and fluffy nature of the material made it feasible for four people to build the entire system by hand in two days without the use of a tractor.

Thirty-five cubic yards of material, 65 straw bales, and 900 feet of 1-inch PEX tubing were used to build the system, along with an estimated 2,000 gallons of water. It had a 12-foot diameter inside the straw bales and was about 7 feet tall when complete.

This system achieved the highest temperatures of any compost power system to date, we believe because the material was such a fine and light texture, enabling massive microbial culture and aeration. After three weeks the 36-inch temperature probe stuck in the top was reading 180°F; a week later it read 189°F! If the temperatures had gotten above 195°F, we would have been at risk of spontaneous combustion.

This was the first time we had to wonder about that possibility, as buildings and grounds inspectors were concerned about it.

The rule of thumb to avoid spontaneous combustion in mounds of sawdust or wood chips that most lumberyard operators go by is to keep the piles below 20 feet in height and to keep them dry if possible. The Evergreen project eventually settled down to temperatures in the 120 to 140°F range. Of course once water is circulating through the heat-exchange loops inside the mound, the likelihood of spontaneous combustion is minimal—the circulation pulls heat out of the mound.

fully compost, and put out heat for a much longer period of time, yielding much more total recoverable energy per ton of material than do manure or food-waste feedstocks.

Ten thousand Btus per hour from one 40-cubic-yard (20-ton) Jean Pain shredded wood system over an 18-month period equates to 129 million Btus. Those 20 tons of woodchips would yield about 160 million Btus of heat energy if burned in a 100 percent efficient woodstove. But since most combustion is at best 75 percent efficient, more energy can potentially be

Steaming compost windrows at a commercial compost-production site.
BRUCE FULFORD

gained by compost-heat recovery of this material than by simply burning it.

The energy recoverable from 20 tons (40 yards) of wood via Jean Pain–style compost-heat recovery over an 18-month period amounts to 6.4 million Btus per ton of material. The cost of 1 million Btus from propane is approximately $30.

Manure- and food-scrap-based compost-heat-recovery systems using the Isobar method can capture 1,000 Btu/ton on average for a 60-day period, or about 1.4 million Btus total per ton of feedstock. Woody feedstocks appear to have more than four times the energy value per ton of material than do manure and food-waste feedstocks.

Feedstock Blends for Jean Pain–Style Systems

Compost Power's projects have determined several different ways to approach using woody feedstocks in modified Jean Pain systems. Key modifications include using perforated aeration tubing in the lower sections of the mounds, under the material, to facilitate passive aeration, as well as using various blends of different types of wood chips, mill shavings, bark mulch sawdust, and sometimes a small amount of animal manure to achieve results similar to those of Jean Pain's systems.

The primary reasons that some of Compost Power's attempts at re-creating Jean Pain's method have failed to produce sustainable heat have been:

1. Use of rot-resistant wood species such as hemlock, cedar, and so forth.

2. Use of large-diameter wood chips without blending with sawdust or fine particle materials. (Much of the food for the microbes is locked inside the wood chips, not available to the process.)

3. The material dried out over time or was not soaked with enough water in the beginning.

4. In some cases when bark mulch was used as the only material, too much water made the material too dense for air to pass through.

As of this writing, Compost Power concludes that the ideal stand-alone materials available from existing processing equipment are stringy shredded wood chips with the texture of bark mulch, or fine, thin mill shavings.

Even if this texture material is readily available, it is still advisable to have up to 30 percent of the material in a system being sawdust and up to 10 percent being manure, blended in with the primary material.

Regardless of texture, the most important variable with composting woody materials for heat recovery is to avoid rot-resistant species of wood such as cedar, hemlock, black locust, redwood, and Douglas fir. Each of the known rot-resistant species has a different level of resistance. For example, it's likely that Douglas fir is a viable feedstock when used in a certain percentage.

Determining which wood species are best for compost and heat recovery, and what the tolerable percentages of each rot-resistant species in a system are, is important future research.

Most wood chippers commonly used by forestry and tree service companies produce large-diameter symmetrical chips, not the stringy fibrous material Jean Pain used. But Compost Power projects have had much success in using a blend of regular wood chips, sawdust, bark mulch, and manure.

Systems made with 60 percent mill shavings, 30 percent sawdust, and 10 percent manure have achieved the highest sustained temperatures—in the range of 140 to 180°F, with higher temperatures during the first three to four months.

Systems made with typical large-diameter woodchips as 50 percent of the material, with 40 percent sawdust and 10 percent manure, have also achieved strong heat results in the 12- to 18-month range, albeit at lower temperatures in the 110 to 140°F range.

Eric Brattstrom and Dotty Kyle

In autumn 2012 Eric Brattstrom and Dotty Kyle of Warren, Vermont, hosted a Yestermorrow Design/Build workshop for Compost Power that I taught. Their goals were to supplement their solar hot water and the radiant floor heating system of their home while also heating their chicken coop.

Eric built a three-wall insulated below-grade concrete bunker underneath the chicken coop, with one end accessible to his tractor. It was sized to hold 25 cubic yards of a Jean Pain–style compost feedstock. He made several hatches in the floor of the chicken coop for access to the compost power system, so that whenever the coop is cleaned out the material can be added to his compost below.

During the workshop students installed perforated aeration tubing in the floor, which was connected to a vertical 4-inch PVC pipe at each end of the container. This allowed air in and under the compost.

The feedstock for this project was a mixture of wood chips and sawdust. The construction process was to simply dump wheelbarrow loads of material down the floor hatches of the chicken coop while a couple of people spread it around and soaked it on top of several layers amounting 600 feet of polyethylene heat-exchange tubing.

Eric Brattstrom with his wife, Dotty Kyle
COMPOSTPOWER.ORG

Students also built an insulated conduit/trench between the house and the compost power system, using foam board and caulking to insulate the water lines and keep groundwater away.

Systems made primarily out of shredded bark mulch have usually performed poorly in terms of sustained high temperatures in winter months. We believe this is because the material becomes overly compacted, restricting passive aeration. Large windrow piles of bark mulch at compost production facilities often maintain internal temperatures above 140°F for at least six months. But it seems that the act of building a modified Jean Pain system out of this material ends up

Brattstrom project below-grade compost power aerated bunker COMPOSTPOWER.ORG

Insulated trench COMPOSTPOWER.ORG

It was determined after the project was completed that all of the sawdust used was hemlock, despite what the supplier had said earlier. This resulted in the temperatures in the compost hovering between 90 and 100°F, which was disappointing.

However, one of Eric's goals was to see if he could get useful heat for two winters on one batch of materials, meaning it would have to last at least 18 months since it was built in October. Even at these lower temperature levels, that heat would be useful for preheating his hot water in the winter while keeping the chickens warm. Because hemlock takes a long time to break down, this 50 percent hemlock material may have been a good choice after all, providing useful heat for two winters.

packing it down too much for passive aeration to keep the microbial culture fully active.

Bark mulch is often the most expensive feedstock to purchase, so Compost Power generally has moved away from recommending people rely on it as a primary input. Much of the bark mulch available is made for the landscaping industry out of rot-resistant materials such as cedar and hemlock, specifically because these species take a long time to break down,

Bioforsk Økologisk

Joshua Cabell, research technician at Bioforsk, an organics research nonprofit in Norway COMPOSTPOWER.ORG

In 2012 Norwegian sustainability experts at Bioforsk Økologisk reached out to myself and Compost Power, having heard about the network from mutual friends and students at the University of Vermont. Joshua Cabell designed and built a modified Jean Pain–style system with detailed guidance from Compost Power in the spring of 2013, aiming to provide hot water to heat a small greenhouse.

Cabell's initial project report is reprinted below, with permission.

COMPOST ENERGY AT BIOFORSK ORGANIC FOOD AND FARMING DIVISION, TINGVOLL, NORWAY

Inspired by experiments of friends and colleagues such as Ben Falk at CompostPower.org and Whole Systems Design, we decided to build a compost heating system of our own at our research station in Tingvoll, Norway. Coastal Norway is blessed with an abundance of natural resources, with one exception – heat. Being located on a fjord near the west coast is both a blessing and a curse. It means that we enjoy relatively mild winters and are able to grow a surprising diversity of fruit and vegetables despite being only four degrees of latitude from the Arctic Circle. The flip side is that summers can be cool and instable, depending on the year's weather patterns. This makes it almost impossible to know how certain crops will do from year to year, particularly those that are on the edge of their comfort zone.

What limits the growing season here is not excessive cold, but the lack of heat. When the sun shines it is extremely strong and days are nearly 20 hours long near the solstice. However, the Gulf Stream, our proximity to the ocean, and predominantly low pressure weather patterns mean that we have a lot of days of cloud cover and precipitation. While this may be great for grass and tree growth, it is not conducive to vegetable production. As such, we decided to experiment with heating a small greenhouse using the technique originally developed by Jean Pain—by capturing and transferring heat generated by the aerobic decomposition of organic material, namely wood chips and animal manure—to give us a head start on the short summer.

After consulting Gaelan Brown from Compost Power and other

sources, we decided to try a 1:1:1 mixture of wood chips, straw bedding from a dairy barn, and sawdust. These are also materials we have readily available either at or near the research station. Among other things, the research station has a working dairy farm with approximately 25 milking cows and as many as 15 calves of various ages.

Straw is used as bedding material for the calves and is cleared out every few weeks. Saturated with manure and urine, it is usually dumped onto windrows and left to rot on its own, and occasionally spread on fields as fertilizer. The center is also surrounded by young deciduous forest, which the farmer is clearing in an effort to expand pasture area. This results in an abundant supply of saplings and small trees that can be converted to wood chips. Finally, the surrounding region has several small-scale saw mills that generate sawdust. This can be easily picked up and is either free or inexpensive (mill operators are often happy to have someone get rid of it for them).

We began by chipping a mixture of deciduous pioneer tree species: birch, aspen, hazel, alder, and mountain ash (rowanberry). We used a Junkkari 260 wood chipper. The trees had been cut and piled in late summer 2012 and left exposed to the elements until we chipped them in mid-April 2013. We made approximately 16 m^3 of chips.

Next we collected about 16 m^3 of straw bedding from a windrow beside the dairy barn. This had been collected over a period of a winter, and what we collected was the most recent to have been cleared out. It was also exposed to the elements, though normally the windrows are covered with tarps to prevent leaching of nutrients. Finally, we needed sawdust. As mentioned, there are several sawmills in the area that produce abundant amounts of sawdust

Wood chip production at the Bioforsk compost power project BIOFORSK

LEFT: *Wood chip production at the Bioforsk project.* BIOFORSK

RIGHT: *Mixing the feedstock for Bioforsk's project.* BIOFORSK

and the intention was to collect from one of them. However, due to a lack of time and ease of collection (the sawdust falls under the mill necessitating that one crawl under with a shovel) we purchased bags of sawdust. In the future we would prefer to get sawdust locally.

On the 23rd of April 2013 we built the compost pile with four people and the help of a tractor and a machine called a Gafner manure spreader (www.gafner-streuer.ch/spreaders/trailer-spreader), which chops, blends, and spreads solid material—perfect for this application. Using the tractor, we loaded equal numbers of buckets of each material into the Gafner (which was hitched to second tractor) until it was full, then spread the mixture onto the site of the pile.

The Gafner has a rotating wheel of blades that chop and blend manure (or in this case wood chips, straw and sawdust) very effectively and an outlet that can be adjusted. At the bottom of the pile we laid down a 5cm layer of wood chips and four parallel sections of drainage pipe, with the ends extending beyond the straw bales containing the pile to allow for air to enter. This was intended to help with drainage and aeration (a second layer of four pipes running perpendicular to the first layer was added to the middle of the pile).

Embedded in the pile is approximately 100 meters of black poly pipe (34mm?) which acts as the heat exchanger. We coiled the pipe

LEFT: *Building the Bioforsk compost power mound.* BIOFORSK

RIGHT: *Watering the wood chips.* BIOFORSK

after each round with the Gafner, which proved to be more challenging than expected. Despite our best efforts to be orderly the pipe managed to get tangled and kink. As it turns out we did not to a very good job of installing the pipe and as I will explain later I had to remove the top half of the pile and re-install the pipe.

It took about four hours with four people to build the pile, which is much faster than references I have seen for other examples. No doubt having access to a bucket loader and the Gafner saved us a lot of time and produced a very well-blended compost pile.

In the first days after the pile was built the temperature climbed to almost 70°C in certain pockets, and maintained this temperature for about a week before dropping to around 60°C. Again, based on recommendations from Gaelan, we decided to use an old insulated milk tank (500 L) to serve as a heat bank. This turned out to be a very important component of the system.

He also recommended that we install a heat exchanger in the tank to carry heat into the greenhouse on a separate loop, but that would have required installing a second pump. Instead, we installed a second loop connected to the main line between the compost pile and the tank that runs through the greenhouse. This was a type of flexible, corrugated hose normally used for housing electrical wires, but worked

Compost-heated greenhouse experiments by Biorforsk in Norway
BIOFORSK

well for this purpose (with the exception that it is quite vulnerable to punctures).

We installed a Wilo circulation pump (.20 A and 43 W at its lowest setting) between the tank and the pile. At the two junctions between the two water lines we installed valves which allowed us to alternate between circulating water directly from the tank to the pile, or from the pile to the tank via the greenhouse.

This solution works great with the exception that it is dependent on someone monitoring the temperature in the greenhouse and opening and closing the valves manually – not always possible on weekends or evenings particularly when the weather is constantly shifting.

As alluded to before we were not very attentive to the placing of the poly pipe in the pile. That fact became clear when we ran our first test once the system was hooked up. For the first five minutes of running water through the pile it came out hot and we were elated. Then the temperature quickly dropped. We waited to let the pile regain heat, and again the temperature dropped.

After repeated efforts to warm up the water slowly, and despite the fact that the temperature in the pile was hovering between 50–60°C, we never managed to get the water more than lukewarm. About two weeks after we built the pile we removed the top half and rebuilt it, this time paying close attention to lay the pipe in an even and well-distributed coil. This had an immediate effect on the pile's capacity to heat the water and was a valuable lesson in the importance of installing the pipe properly. Further modifications include insulating all exposed pipes and joints and installing an insulated lid on the tank. These helped to reduce heat loss between the compost pile and the tank.

We leave the pump running continuously to circulate water between

the tank and the pile. When circulating directly between them the water temperature hovers around 40°C, regardless of the outside temperature. On days that are cool or cloudy we open the valve to the line going through the greenhouse, which has had an obvious effect on the inside temperature.

As can be seen in the data collected even on days where the outside temperature is below 15°C it can be in the mid-20s in the greenhouse. After some hours of circulating through the greenhouse the water temperature dropped, but never below 30°C. When the sun returns or the day is warm enough we close the valve to the greenhouse and circulate the water directly to the tank in order to raise the temperature again. As mentioned before, this requires constant monitoring.

Ideally we would have the valves steered by a thermostat, closing the line to the greenhouse when the temperature reached a certain level. With such a modification we feel that the set-up would work very well, at least during spring and early summer when there are occasional warm and sunny days, but it remains to be seen how it works during colder months.

Cabell's project gained some local media coverage, and the articles were seen by the operator of several large fish hatcheries in Norway. New laws will prevent hatcheries from dumping the fish sludge (manure) from their smolt tanks into rivers, as they have been doing historically. The fishery operator is now exploring, with help of people from Compost Power and Agrilab, opportunities to mix the fish sludge with forest residues and compost the material while capturing heat that would be used to keep the fish tanks warm, as well as to heat greenhouses.

which is what makes them effective as decorative mulch in gardens.

Similarly, systems made entirely out of sawdust tend to get overly compacted, which restricts passive aeration.

Regardless of the texture and species of woods used for Jean Pain–style compost-heat-recovery systems, it's paramount that the material is thoroughly soaked with water and that measures are taken to ensure the material does not dry out below 40 percent moisture content.

If negative aeration is employed with woody feedstocks, it pulls a lot of hot steamy air out of the material. Once the moisture content drops below 40 percent, the composting microbes go into a hibernation period and the thermal output of the system collapses.

In theory, negative-aeration heat exchange from this shredded woody material makes a lot of sense, as long as the material can be continually re-moistened. The texture of the material would make it easy to pull air through, and the lack of odors contained in that hot air would make it attractive for direct use in heating applications. To my knowledge there has been minimal research done on this particular approach.

Manure, Food-Waste, and Agricultural-Waste Feedstocks

With composting systems that use varieties of materials, such as food waste, agricultural waste, and animal manure, a bulking agent is usually blended in during the beginning of the process. Bulking agents help to bring more carbon into such materials. Food and manure feedstocks are high in nitrogen but low in carbon.

Typical bulking agents are wood chips, sawdust, bark mulch, and straw; these are thoroughly mixed into the high-nitrogen inputs. This helps capture moisture that would otherwise run off. Bulking agents also enable consistent aeration throughout the material. The aeration factor is especially important in aerated static pile systems that accomplish aeration without regular mechanical tumbling of the compost.

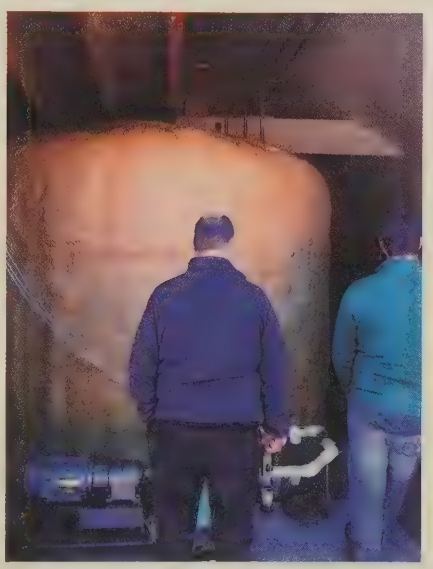
The various recipes and blends of compost feedstock are nearly infinite. Everything from fish manure sludge left over from hatchery operations, to slaughterhouse waste, coffee chaff, and even burlap bags can be blended with other materials and effectively composted while heat is recovered from the system through negative aeration.

Chapter 9

Integrating with Other Systems

Biogas

Creating biogas is an anaerobic process, with a different microbial culture feeding on different elements of the feedstock and producing natural gas as a by-product. Jean Pain showed one way to integrate biogas generation with compost-heat recovery. Since biogas systems need to be kept at around 100°F to operate, and since feedstocks that can be composted can also be digested, it makes sense to integrate compost-heat recovery with any scale of biogas production.



The anaerobic biogas digester at Jasper Hill Farm is kept at the ideal operating temperature of 100°F by heat captured from compost. AGRILAB TECHNOLOGIES

To my knowledge, Jasper Hill Farm is the only example on the planet of industrial-scale biogas generation being integrated with compost-heat recovery to keep the digester warm. Many farms are using the digested "cake" left over from digesters as bedding in their barns, because the material is odorless, absorbent, and low in pathogen potential.

However, once animal manure or other feedstocks have gone through a digester, the cake can still be composted in a short thermophilic cycle that will produce additional energy in the form of heat while making higher-value material for fertility, or for animal bedding. Conversely, materials can be partially composted first, capturing large amounts of heat energy during the first four-week cycle, and then that material can be digested, producing valuable natural gas.

Jason McCune Sanders

Jason McCune Sanders was one of the engineers who helped launch Avatar Energy, a company that builds small-scale biogas digesters for farms, in the early 2000s. He later went back to finish his engineering degree and became a leader of the Compost Power Network and the lead engineer at Agrilab Technologies.

Sanders took a very active role in Compost Power, helping people do backyard experiments and lending his engineering skills to the group. He also performed his own tests by composting different types of wood chips, through the consulting practice he founded, Forest Enterprises.

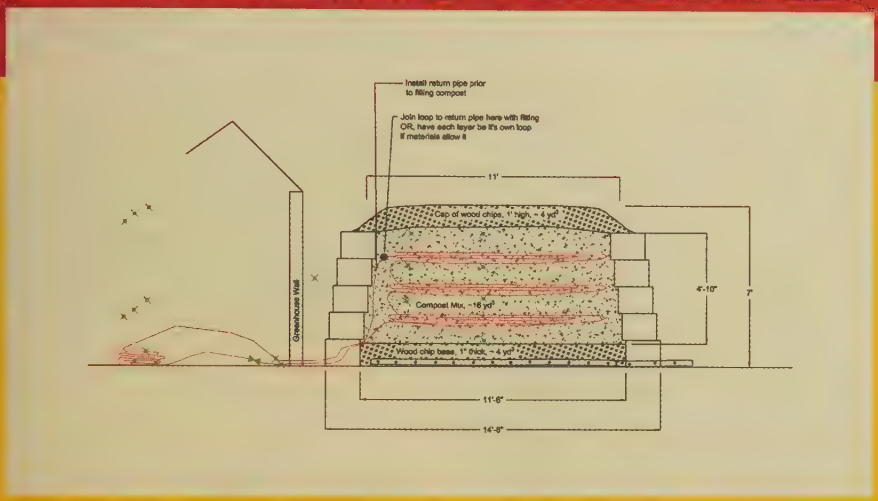
Early on Sanders realized the importance of the texture of wood chips in terms of how actively the material would compost and generate high temperatures. Many of the early projects struggled to find the kind of small-diameter or fine stringy wood chips that put out the most heat.

So Sanders bought a special wood chipper—called a Valby—whose adjustable knives create very small chips. He started lending and renting it out for projects along with doing more of his own backyard research.

In 2010 Compost Power collaborators including myself, Sam Gorton, and Sanders worked with a few groups of students at the University of Vermont to propose on-campus research and demonstration of compost-heat recovery. In late 2011 a three-year grant was awarded to be

Jason McCune Sanders next to the Isobar array at UNH's compost-heat-recovery system COMPOSTPOWER.ORG

Sanders inside the compost-heated greenhouse at the Hort Farm, University of Vermont, demonstration project phase 2. AGRILAB TECHNOLOGIES


Install return pipe prior to filling compost
Join loop to return pipe here with fitting OR, have each layer be it's own loop if materials allow it
11'
Cap of wood chips, 1' high, ~ 4 yd³
Greenhouse Wall
Compost Mix, ~16 yd³
4'-10"
7'
Wood chip base, 1' thick, ~ 4 yd³
11'-6"
14'-9"

CAD Drawing of the Compost Power mound built at Slade Greenhouse

spent on campus-directed research, with a $25,000 annual budget.

The first UVM project, in which Sanders played a leading role, was to build a modified Jean Pain system to heat the winterized Slade greenhouse on campus, which was being revitalized. Sanders and I consulted with UVM staff on design and material planning, including sizing the system, making engineering drawings, and creating an extensive data-logging package. Sanders also used his chipper to supply some of the materials and worked with the UVM dairy farm and other sources to test a blend of materials including mill shavings, wood chips, sawdust, and a little bit of manure.

UVM Hort Farm compost heat recovery bin being loaded AGRILAB TECHNOLOGIES

The final ratio of materials ended being 25 percent small-diameter wood chips, 25 percent mill shavings, 40 percent typical tree service wood chips, and 10 percent fresh manure.

I led a two-day hands-on workshop to teach a few dozen UVM students about compost-heat recovery while building the system. Many of the students who participated in the classroom and hands-on aspects of the workshop lived in the Slade dormitory, which had its own kitchen

UVM Hort Farm compost heat recovery ductwork in greenhouse; it channels hot steamy air directly into a biofilter of mature compost under the seedbeds
AGRILAB TECHNOLOGIES

UVM Slade compost power project heat-exchange tubing COMPOSTPOWER.ORG

Technicians water the material at the nearly complete UVM Slade project.
COMPOSTPOWER.ORG

that used food grown in the compost-heated greenhouse next door.

The design included the use of hay bales as insulating side walls, creating a structural blanket around the composting "hot mix" in the mound. To encourage passive aeration of the composting material, six 20-foot-long perforated PVC pipes were laid in a cross pattern on the ground before any material was laid out. The ends of each pipe were stuck in between gaps in the hay-bale side wall.

Six hundred feet of 1-inch PEX tubing was distributed across five 10-inch layers of material in the 35-cubic-yard mound. Thousands of gallons of water were added to the material as it was spread around on top of each layer of PEX heat-exchange tubing. By the end it looked like a hay-bale igloo; students had a bit of a dance party on top as it was finished.

The supply/return lines of PEX tubing in the compost were integrated into the new radiant floor heating system in the seedbeds and greenhouse. The north wall of the greenhouse was lined with eight 50-gallon black plastic barrels that would store solar energy and provide additional heat to the greenhouse at night.

Slade greenhouse compost power experiment during construction COMPOSTPOWER.ORG

Electrical and monitoring controls at the UVM Hort Farm's compost-heated greenhouse AGRILAB TECHNOLOGIES

Several sensors were distributed inside the mound as it was built, with wires carefully laid out to a central conduit point where they would connect to the data logger in the greenhouse. The data logger would track the temperature of several locations inside the mound, as well as of the supply/return water lines coming into the greenhouse, and greenhouse temperatures.

Within two weeks, by mid-November, the temperature readings in the mound and water lines ranged from 110 to 130°F. Students and faculty were abuzz with emails going out showing the links to the data-logger webpage. Unfortunately the greenhouse renovations were not complete for several more weeks.

The first month of tracking the temperatures revealed an interesting thing: The hot inner core area of the mound, which had been in the central area, had moved up to the top. The lower sections of the mound, which had been in the range of 110°F-plus initially, had now cooled to 100°F or less.

Other similar systems that had used one long section of flexible perforated pipe with only one end open to the outside air had not seen this issue. By tracking the changes daily it became evident that there was too much aeration, too much "chimney effect," which was making a lot of heat move up and out of the material, because there were 12 open ends of 4-inch aeration tubing bringing cold outside air into the bottom of the mound. So we partially blocked the ends of each pipe to restrict airflow.

Temperatures in the mound did improve after that, but by the time the greenhouse was ready to be used, someone had accidentally punctured the PEX tubing in the mound with a compost thermometer. This was very disappointing to say the least.

The punctured pipe meant the mound had to be partially torn down and the PEX repaired. The act

UVM Hort Farm compost heat recovery ductwork in greenhouse; it channels hot steamy air directly into a biofilter of mature compost under the seedbeds
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Agrilab Technologies' Isobar Heat Recovery Unit AGRILAB TECHNOLOGIES

of tearing apart and haphazardly rebuilding a section in midwinter disrupted the microbial culture. Compost temperatures didn't recover until the spring. It turned out that the greenhouse operation plan fell apart regardless of the compost system, so nothing was ever planted.

In 2013 UVM began a two-year renovation of the Slade dorm, which has left the Slade greenhouse temporarily off limits. The current phase of compost-heat-recovery research at UVM is being led by Bruce Fulford. Sanders, and UVM staff led by Michelle Smith, and is described in the sidebar on Fulford in chapter 3.

Sanders now works as the lead engineer for Agrilab Technologies. He has redesigned the Isobar heat-exchange and control systems, which had previously been built into large separate utility rooms. This enables the entire system to be housed in mobile shipping containers, which significantly improves project finance options including lease-to-own programs.

In most large-scale biogas systems, the waste heat from burning the gas is used to keep the digester at the ideal temperature for methane production (100°F). But in some cases it makes sense for compost-powered heat to be used to keep a digester warm, particularly in small-scale systems.

The potential for "cow power" and other biogas digesters of any scale to be integrated with compost-heat-recovery systems is enormous. (See compost heat/biogas digester integration flow chart, page 25.)

In-Vessel Composting

During the past 20 years several companies have created innovative in-vessel composting systems designed primarily for managing materials

Vertal, Inc.'s CityPod in-vessel compost system for urban on-site composting. A redesign is being explored in partnership with Agrilab Technologies so it will also be able to capture heat.

and the composting process in space-constrained or urban and suburban environments. These containerized composting systems come in many configurations and sizes, from backyard tumblers to large, highly engineered systems at an industrial scale.

UVM Slade compost power project, completed COMPOSTPOWER.ORG

Two great examples of innovators in this space are Vertal, Inc., based in Montreal, Canada, and Green Mountain Technologies, based outside Seattle, Washington, in the United States. Both companies have developed many containerized composting systems that are designed to continuously take new material and continuously produce high-quality compost with automatic material handling systems and odor-capture/reduction systems.

Many in-vessel composting systems use active aeration that either pushes or pulls air through the

Conan Eaton

Conan Eaton, the owner of Auburn Star Farm in Lunenburg, Vermont, is another very interesting self-educated tinkerer who figured out an effective way to use compost-heat recovery to save thousands of dollars per year in heating fuel costs. He operates a dairy farm with 240 Holsteins that have a bedded pack system and a liquid manure system. He runs the liquid manure through a process to separate the solids and reuses most of the composted separated solids as bedding in the barn, dramatically reducing his bedding (sawdust) costs.

Since 2010 he's been using raw separated manure and compost as bedding with no health problems in his herd. This dramatically goes against conventional thinking, but his measurements of pathogens and bacteria in his herd have never been lower. He cleans the stalls and barn twice per day, removing all wet material, and sometimes adds hydrated lime to the bedding in the summer. This results in higher-quality compost and helps prevent the compost from being too wet to use for bedding. He had to make several of his own modifications to the experimental manure solids separator, which earned him a "certificate of Shitology" from the engineering firm that built it.

He built his compost-heat-recovery system after teaching himself the basics and getting inputs from those

Conan Eaton and James McSweeney give a tour of Conan's compost-heat-recovery system COMPOSTPOWER.ORG

Conan Eaton's dry separated manure, ready to be composted or used as bedding COMPOSTPOWER.ORG

Eaton's shitology certificate
COMPOSTPOWER.ORG

Eaton's compost-heat-recovery shed, aka hot box of shit COMPOSTPOWER.ORG

involved with Compost Power, Highfields Center for Compost, James McSweeney in particular, and friends in the waste management industry.

His system is basically a narrow and long insulated building, affectionately known as "Conan's Box" in Compost Power circles, that is designed to make it easy to load and unload compost materials with his tractor. It's got a 10-inch-thick concrete slab floor where 1.5-inch perforated PVC aeration pipes are laid in 3-inch-wide channels. He filled the channels around the PVC pipe with 1.5-inch crushed stone to encourage airflow and allow drainage.

The building is 12 feet wide, 10 feet tall, and 42 feet long. It's built out of 2x8 studs and well insulated, with 1,200 feet of 0.75-inch poly tubing spread on the inside of the ceiling, spaced 6 inches apart. The poly tubing is his heat exchanger, with water circulated through the tubing being warmed up by the hot air that accumulates on top of the compost. The heat-exchange tubing

Heat-exchange tubing in the ceiling of the shed
HIGHFIELDS CENTER FOR COMPOSTING

in the ceiling is in three separate zones; these are connected to a manifold that makes the water in each zone reheat quickly.

Eaton keeps water circulating at 6 gallons per minute between the

Aeration ducts in the compost-heat-recovery shed
HIGHFIELDS CENTER FOR COMPOSTING

Water circulation flow meter
COMPOSTPOWER.ORG

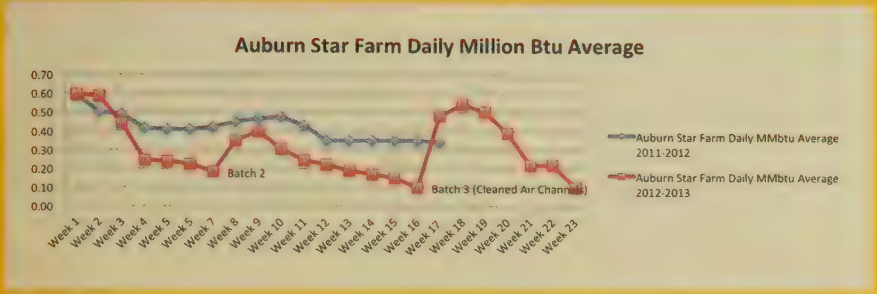
Compost aeration fan COMPOSTPOWER.ORG

heat-exchange zones in the ceiling and heat exchangers in his buildings, tracked by a flow-meter on the water line, capturing between 20,000 and 30,000 Btu/hr continuously.

The PVC pipes in the floor are connected to a 75-watt air blower that cost him $125. This blows air up into the material, keeping the compost process active without requiring stirring and turning of the material. The air inlet to the fan comes from the top of the box, recirculating the air with a valve he opens partially to let in some outside air. When asked, "How much air comes from outside?" he replies with the certainty and precision only a Vermont farmer can exhibit: "Not too much."

He uses dampers to adjust airflow based on the temperatures of the material, aiming for 130 to 150°F, but often the temperature of the compost exceeds 170°F.

Eaton loads 120 cubic yards of blended manure and bedding into the box per batch, leaving about 2 feet of headroom inside between the top of the compost and the ceiling. The water temperatures he's able to



Btu capture data from Eaton's hot box of shit HIGHFIELDS CENTER FOR COMPOSTING

Compost on aerated heat-recovery pad at Sunset View Farm COMPOSTPOWER.ORG

sustain in the heat-exchange tubing in the ceiling range between 100 and 135°F. He reports higher temperatures when the fan is running constantly. Eaton says the temperature of his compost peaks after 4 to 6 weeks, but he leaves each batch in for 8 to 12 weeks because there's still plenty of useful heat during the second half of the process.

Eaton uses the hot water to heat a large workshop building that also houses his manure separator. He uses an old tractor radiator with a three-speed fan behind it, with compost-heated water constantly circulating through the radiator, to heat the entire building. He says he's saving about $2,000 per year on oil fuel and uses absolutely zero fossil fuel to heat the 1,600-square-foot building. Recently he built a new greenhouse and is planning to install radiant heating zones in the seedbeds for early-spring planting while running the hot exhaust air from his compost aeration system into the greenhouse. "We'll just keep it simple and see if we can keep making it work," he told me in an interview.

External view of the Earth Flow in-vessel compost system by Green Mountain Technologies. GREEN MOUNTAIN TECHNOLOGIES

material. Most also have built-in mechanical systems that stir and tumble the material, using augers, conveyors, and other means. The most advanced systems also have automatic ways to add bulking agents such as sawdust or wood pellets to the system as food scraps or other high-nitrogen food wastes are added to the container.

In-vessel systems enable the compost-production process to happen at the source of the material, right next to the location where the food scraps or agricultural wastes are generated.

The more advanced industrial-scale systems use negative aeration, pulling air down through the material, and run the exhaust through a biofilter to remove odors. Sometimes enzyme catalysts are added to the material to reduce odors, which are a primary concern among most commercial-scale compost producers, especially in urban environments.

The potential for compost-heat-recovery systems such as the Containerized Isobar Unit from Agrilab to be integrated with in-vessel compost systems is enormous.

There are also research-and-development projects under way to combine containerized composting vessels with heat-recovery processes that can capture and eliminate odors.

These two technologies open up many opportunities to distribute the production of compost in places where food waste is generated (eliminating much of the transportation costs to landfills or compost facilities) while also using the heat energy that can be captured on site. Since most of the in-vessel composting systems handle less than 5 tons of material at a time, existing heat-recovery technologies such as the Isobar system would have to be tied into multiple composting vessels, or downsized to fit the amount of material in production.

At the residential level, much potential exists for containerized compost production and heat recovery. A roll-off Dumpster that is 20 feet long and 8 feet wide/high (with cedar shingles to make it look suburb-ready), for example, could contain approximately 40 cubic yards of composting material and potentially be modified with insulation, aeration, and heat exchange to provide 10,000 to 20,000 Btu/hr.

This is enough energy to heat the average home in winter climates. Most homes don't produce anywhere near that amount of compostable food scraps, but forest and yard residues and other materials could be brought into the equation.

Another viable option for permanent residential compost-heat recovery is to build an insulated box, such as Conan Eaton's, or to build a below-grade bunker with insulated concrete or insulated cinder blocks. Aeration channels could be built into the floor, for either passive or active aeration, and hydronic heat-exchange tubing can be achieved with the Jean Pain approach of coiled water lines, or with modular heat-exchange zones affixed to "cattle panels" or other structures to make the build/rebuild process faster.

Afterword

During the research and writing of this book I was barely able to keep up with the ongoing innovation around the concept of compost power. I've been directly involved in many of these innovations and projects, and every project has taught us new things. But every time I search the web for "compost power" I find new examples of people applying the concept in different and sometimes very interesting ways.

There are also a lot of backyard tinkering and compost power projects that are not publicized online or in traditional media outlets. I just heard about a landscaping company that keeps their greenhouses operating through Vermont's winter with a modified approach to the Jean Pain method, with water lines coiled through the very large piles of bark mulch that they sell as landscaping material. They've been doing this for many years.

Recently I started helping another inspired college student who found me on Facebook. We're formulating a plan for a compost-heated water system for a college campus in California, using our projects at the Universities of Vermont and New Hampshire and Evergreen State College's compost-heated dorm as examples. At a recent trade show I met with several engineering firms that produce different components of large-scale and containerized composting systems that have immense and immediate potential for integration of compost heat recovery. The week before that I met with a Canadian company that builds automatic compost-production vessels for urban sites that will have heat-recovery systems built in by the middle of 2014. This will enable a restaurant or cafeteria to reduce their hot water costs while eliminating the cost of removing food waste by instead selling that material as finished compost.

In February of 2014 we kicked off a feasibility/design project for a large zoo at a city in the upper Midwest in which we'll use "zoo poo," animal manure and food waste, to produce compost that will feed the soils in new greenhouses that will grow food for the zoo animals. And the greenhouses

will be heated through the winter with an Isobar compost-heat-recovery system. We're in discussions with several poultry farms in the United States and a very large fish hatchery in Norway that currently spend a lot of money removing their manure waste to prevent watershed pollution while they spend enormous amounts of money on heat during the winter months.

By the spring of 2014 Agrilab Technologies plans to launch a compact containerized Isobar system with 50,000 Btu/hr of heat recovery potential under a lease-to-own program for small farms or homesteads that have only 30 to 50 tons of compost feedstock available every 8 weeks (the equivalent of 12 to 20 cows or horses).

By the time you have read this, there will undoubtedly be many new examples and innovations around this idea that are not included in this book, including some very interesting commercial/business enterprises that are springing up even as I write. I will continue to maintain CompostPower.org as an open source nonprofit research network offering resources and advice and attempting to maintain best practices information. Highfields Center for Composting is also a great place to get information about best practices. I invite you to visit www.CompostPower.org or www.Agrilabtech.com and to contact me with your questions by emailing Gaelan@CompostPower.org.

I hope that after reading this book and doing a little research online you'll be saying to yourself "Ok, I want to figure out how to apply this in my life, but there seem to be many different approaches and I'm not clear which approach is best for me. Should I do a modified Jean Pain–style mound with heat-exchange coils embedded in the material? Should I build an insulated box or shed with active aeration systems like Conan Eaton's? Should I look into an Isobar system with negative aeration that pulls heat out of the hot air and vapor from the compost? Should I try negative aeration for greenhouse heating without a heat exchanger and just pump the hot air/vapor into the seedbeds? Should I do a round Jean Pain system or a windrow-style system? How do I know which approach is best for my needs and the compost feedstocks that I have available?"

These are all good and important questions, and there's no simple answer. However, I'd like to give you a list of project-scoping questions to help you define how you can put compost power to work for yourself. Once you've got these questions answered, contact me or inquire through CompostPower.org and I'll be happy to help you.

Key Questions:

1. What exactly are my heating and hot water needs in terms of average daily monthly Btus during each season of the year? What is that costing me over a five-year period? Take your five-year heating hot water fuel costs and earmark that as your project budget for a compost power system.

2. Is my goal to make hot water for washing/domestic/commercial use? Or to heat buildings? Or to heat greenhouses?

3. Do I want to tie into radiant-floor heating systems (which is ideal) or baseboard hydronic radiators? Or hot air convection radiators? Who's a good HVAC/plumber professional to help me with that part?

4. What scale of compost production am I really interested in going into? Do I want to make a part-time or full-time living at making and selling compost? Or do I just want to do as much compost production as I need for my energy goals?

5. If I'm going into commercial-scale compost production and want to include heat recovery, should I do a negative aeration system, containerized aerated systems, indoor or outdoor systems?

6. What compost feedstocks do I want to work with and have access to? Do I want to focus on forest residues, animal manure waste, humanure, agricultural waste, food waste, yard waste, or a combination? How do I ensure I've got reliable sources of these feedstocks?

7. Do I want a compost power system that is low-tech but has high labor requirements, or an approach that uses the best available technology while minimizing labor and maintenance needs?

As you can see, many of these questions are the same questions that you'd need to answer if you were building a business plan for a compost production sales company. Given the growing market demand for compost and the

massive need to divert biomass wastes from landfills and waterways, I cannot recommend highly enough for any enterprising person to look closely at composting as a business. But residential-scale compost power can also be viable. Now that you know it works, it's up to you to make it happen.

Bibliography

These additional research references have been provided by Bruce Fulford (*NAI Compost Heated Greenhouse Report*, 1986).

Cooney et al. (1968) found that thermophilic bacteria will generate 4 watt-hours energy per gram of oxygen used (6,190 Btu/lb O_2 or 14.4 x 106 J/kg O_2). These findings are corroborated by Svoboda and Evans (1983), who report 4.03 kwh/kg O_2 used by bacteria (6,240 Btu/lb O_2 or 14.5 x 106 J/kg O_2) in composting farmyard manures.

Danish researchers Vemmelund and Berthelsen (1979) have achieved 550 kilocalories per hour per cubic meter (1,660 Btu/yd^3/hr or 2.30 x 106 J/m^3/hr) of composting farmyard manures in mechanically agitated cubicles with forced aeration. Sardinsky (1979) finds the probable outputs from a metric ton (2,200 lbs including 50 percent water by weight) of compost to be 3,375,000 Btu, 290 kg CO_2, and 47 liters of water (in vapor) during a 21-day thermophilic stabilization period. (These are equivalent to 1,530 Btu/lb or 3.56 x 106 JI kg, 0.29 lb/lb, or 0.29 kg/kg CO_2, and 0.0056 gal/lb or 0.047 l/kg water vapor.) Quantities of these elements are difficult to standardize, given the diversity of compostable materials and methodologies, but these figures provide reasonable estimates to work from in designing systems to use them.

Svoboda and Evans (1983) and Sobel and Muck (1983) developed equations for analyzing biothermal production from aerated animal wastes.

Thostrup (1982) reports on the heat production from pig manure in slurry form, and Schuchardt (1984) compares several biothermal heat-exchange systems employing flat plate and other fluid-based systems of capturing heat from composting farmyard manures.

Del Porto (1981) describes solar-assisted composting and refers to the use of biothermal heat in composting toilet designs.

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Index

Page numbers in *italics* refer to illustrations.

A

Aber, John, 60
Acrolab Ltd., 13, 46–47, 48, 57, 96
active aeration, 30–31, 34, 45, 137, 142
aeration (air), 30–31
  active, 30–31, 34, 45, 137, 142
  balance of moisture and, 34, 43–44
  negative, 45, 48, 56, 63, 95, 130
  passive, 30–31, 34, 116, 120, 122–23, 134
  texture relative to, 31
aeration tubing, 100, 120
  Evergreen State College project, *77,* 118, 119
  Galt's Gulch, 11–12, *12*
  large-scale Jean Pain system, 89, 91
  small-scale Jean Pain system, 73, 74, 77
  UMass–Amherst Graduate Thesis Project, 52, *53,* 54
  UVM Hort Farm, *41, 42*
  Walker's plan, 103, 104
agricultural waste, 117, 130, 142
Agrilab Isobar systems, 13–14, 16, 20, 45–66
  Diamond Hill Custom Heifers, *49,* 49–51, *50, 51*
  energy yields per hour, 16, 117–18
  feedstock volumes, 48–49
  flow chart, *25*
  Highfields Center for Compost, 60–66, *61–65*
  Jasper Hill Farm, 58, *58, 59*
  negative aeration, 45, 48
  schematic drawing, *45*
  Sunset View Farm, *48, 49,* 54–57, *56*
  University of New Hampshire, Durham, *45,* 59–60
Agrilab Technologies, 15–16, 20, 46–47, 67
Allmand, Mark, 118
alternative heat-exchange system
  large-scale Jean Pain system, 87–88, 90
    step-by-step construction directions, 92–93
  small-scale Jean Pain system, 69–70
    design specifications and elements, 74–75
    step-by-step construction directions, 79–81, 80
ammonia, 36, 43, 48, 110
anaerobic biogas digester, at Jasper Hill Farm, 58, 131, *131*

animal bedding, 23, 24, 35, 42
Auburn Star Farm, 138–41
Avatar Energy, 132

B
bacteria, 34, 35, 110–11, 113
bales, as insulating side walls, 11–12, 70–71, 73, 98–99, 118, 126, 134
bark mulch, 120–23, 130
  Karl Hammer's windrow-style compost power mound, 33
  Smith's compost power project, 18, 19
"bedded pack" approach, 42, 49, 51
Bioforsk Økologisk, 124–29
biogas, 24, 26–27, 131–36
Brattstrom, Eric, 122–23
Brown, Gaelan, 124–25
bulking agents, 30, 35, 42, 44, 130, 142
Burley-Demeritt Farm, 59–60

C
Cabell, Joshua, *124,* 124–29
carbon/nitrogen ratio, 29, 34–35, 42, 130
Carpenter, Ken, *12*
cedar, 118, 120–21, 123
certified-organic fertility, 10
circulation flow rate, 72, 82–83, 88, 93
circulator pumps
  large-scale Jean Pain system, 85, 88, 90, 92, 93
  small-scale Jean Pain system, 67, 72, 81–82
compost bulking agents. *See* bulking agents
Compost Energy Center, 15
compost feedstocks. *See* feedstocks
compost-heat recovery
  brief history of, 7–16, 20
  economic viability of, 22–25, 28
  energy yields, 25, 28
  science of, 29–44
composting process, 22, 29–44
  balance of moisture and air, 34, 43–44
  carbon/nitrogen ratio, 29, 34–35, 42, 130
  feedstock, 34–35, 42–44
  preconditions necessary for process, 30–31, 34
  texture relative to aeration, 31
Compost Power Network (CompostPower.org), 14–17, 20, 104, 117, 120, 121, 132
Cuhls, Heiner, 16, 57, 117

D
data-logger, 43, 135
  large-scale Jean Pain system, 88–89, 92
  small-scale Jean Pain system, 72–73, 81
Design Guide (CompostPower.org), 16
Diamond Hill Custom Heifers, 16, 47, *49,* 49–51, *50, 51*

E
Earle Family Farm, 98–101, *99*
earth coupling, 101–2, 104
Eaton, Conan, *20,* 63, *138,* 138–41
energy yields per hour, 48–49, 117–20
Evergreen State College, 16, *69, 70, 75, 77, 78, 81, 118,* 118–19, *119*

F
Falk, Ben, *8, 10,* 17, *17,* 96, *97,* 104, 124
feedstocks, 29–30, 34–35, 42–44, 116–30. *See also specific feedstocks*
balance of moisture and air, 34, 43–44
Bioforsk Organic Food and Farming, 124–29
biogas production, 131
blends for Jean Pain–style systems, 100, 120–23, 130
Diamond Hill Custom Heifers, 49–51
energy yields per hour, 48–49, 117–20
Evergreen State College's system, 118–19
Galt's Gulch, Chile, 11, 12
Highfields Center, 64–65
Karl Hammer's windrow-style compost power mound, 33
large-scale Jean Pain system, 85, 91, 92
manure, food-waste, and agricultural-waste, 130
NAI compost-heated greenhouse, 35
small-scale Jean Pain system, 68
Smith's compost power project, 18, 19
texture relative to aeration, 31
UMass–Amherst Graduate Thesis Project, 54
food-waste feedstocks, 130, 142, 143
forestry and farming, 23–24
Fulford, Bruce, 15, 20, 35, 36–43, *37. See also* NAI compost-heated greenhouse
fungal cultures, 29–30

G
Galt's Gulch, Chile, 11–12
Gaylord Farm, 98–101, *101*
Gilbert, Tom, 61, *61*
Gorton, Sam, 132
greenhouse heating design, 94–115. *See also* NAI compost-heated greenhouse
best methods of distributing heat, 96–97, 100
projects, 95–96
proper foundations, 101
proper ventilation, 102
small-scale compost-heated greenhouses, 98–101
Walker's design, 102–4
Weiss's methods and projects, 104
Green Mountain Technologies' Earth Flow in-vessel compost system, 137, *142*

H

Hammer, Karl, 15, *32,* 32–33
hay bales, as insulating side walls, 11–12, 44, 52, 54, 70–71, 98–99, 118, 126, 134
hay bedding, 35, 42
heat-exchange systems
  alternative systems. *See* alternative heat-exchange system
  Fulford's NAI greenhouse, 107–8
  Isobar systems. *See* Agrilab Isobar systems
  large-scale Jean Pain system, 86–87, 90, 92–93
  small-scale Jean Pain system, 68–70, 70, 75–79
hemlock, 120–23
Highfields Center for Compost, 15, 20, 60–66, *61–65*
history of compost-heat recovery, 7–9
horse manure, 35, 42, 130
Horticulture Farm at UVM, *38–42,* 38–43, *96, 97, 132–35*

I

in-compost heat exchange
  large-scale Jean Pain system, 85–86, 92–93
  small-scale Jean Pain system, 68–70, 70, 75–79
insulated utility box, 90–91
in-vessel composting, 136–43
Isobar technology, 16. *See also* Agrilab Isobar systems

J

Jasper Hill Farm, 24, *25, 28, 46,* 47, 58, *58, 59, 95,* 96, *96, 97,* 131, *131*
Jean Pain Chipper, 26, *27*
Jean Pain Institute, 15
Jean Pain–style systems, 13, 14–15, 26–27, 116
  Agrilab system compared with, 13–14
  Bioforsk Organic Food and Farming, 124–25
  energy yields per hour, 117, 119–20
  feedstock for, 25, 31, 34, 100, 116, 120–23, 130
  Heiner Cuhls and, 16, 57, 117
  Highfields Center for Compost, 60–61, 63
  large-scale. *See* large-scale modified Jean Pain system
  small-scale. *See* small-scale Jean Pain system
  UMass–Amherst Graduate Thesis Project, 52
Jerose, Brian, *46,* 46–47, 60

K

Kingsbury Farm, *98,* 98–101, *99*
Knapp, Dan, 15
Kyle, Dotty, 122–23

L

large-scale Isobar systems. *See* Agrilab Isobar systems

large-scale modified Jean Pain system, 84–93
operational overview, 93
recommended design specifications and elements, 89–91
recommended system design and system parameters, 85–89
step-by-step construction directions, 91–93
system parameters and goals, 84–85

M

McKibben, Bill, 20
McSweeney, James, 60, *61*, *138*, 139
Magnan, Terry, 47
manure-based composts, 35, 42, 130
manure pollution, 24–25
mechanical stirring, 30
methane gas, 24, 26–27, 136
microbial culture, 14, 27, 29–30, 31, 34, 43–44, 83, 93, 131
moisture level, 34, 43–44, 130
monitoring system
large-scale Jean Pain system, 88–89, 93
small-scale Jean Pain system, 72–73, 82

N

NAI compost-heated greenhouse, 105–15, *106*, *107*
biological performance, 110–12
composting chamber, 105–7
heat transfer system, 107–8
horticultural performance, 113–15
soil quality, 112–13
thermal performance, 108–10
Native Power, 57
negative aeration, 45, 48, 56, 63, 95, 130
Nelson, Josh, *46*, 46–47, 57
New Alchemy Institute (NAI), 15, 35, 36–38. *See also* NAI compost-heated greenhouse
New York State Energy Research Development Authority (NYSERDA), 55–56
nitrogen, 27, 114
biological performance of the NAI greenhouse, 110–12
carbon ratio, 29, 34–35, 42, 130

O

odors, 7–8, 14
organic agriculture, 10, 22
organic compost production, 10, 22–24, 27
Organic Research Dairy Farm (ORDF), 59–60
Oullette, Joseph, 13, *13*, 46, 48, *49*, 57
oxidation, 34–35

P

Pain, Jean, 14–15, 24, 26–27, *27*, 29, 116. *See also* Jean Pain–style systems
passive aeration, 30–31, 34, 116, 120, 122–23, 134

PEX (or polyethylene) tubing
Galt's Gulch, Chile, 12
large-scale Jean Pain system, 85–86
Slade Greenhouse, 134–36
small-scale Jean Pain system, 68
Polar Solar, 18–19
Potwine Neighborhood Farm, 52
poultry manure, 35, 130

Q

Quinn, Sean and Sandy, 54–57

R

raw manure pollution, 24–25
Rynk, Robert, 57

S

Sanders, Jason McCune, *9, 132,* 132–36
sawdust, 34–35, 44, 68, 85, 103, 119, 120, 125–26
Schwellenbach, Garth, 52–55
science of compost and heat recovery, 29–44
Selman, Jesse, 52
side wall structure
Galt's Gulch, Chile, 11–12
large-scale Jean Pain system, 88, 89–90
small-scale compost-heated greenhouses, 98–99
small-scale Jean Pain system, 70–71, 73, 77, 80–81
UMass–Amherst Graduate Thesis Project, 52–53
Slade Greenhouse, 20, 39, 95–96, *133,* 133–36, *134, 135*
small-scale compost-heated greenhouses, 98–101
small-scale Jean Pain system, 67–83
energy yields per hour, 117
operational advice, 82–83
plumbing and operational overview, 81–82
recommended system design and system parameters, 68–75
step-by-step construction directions, 75–81
system parameters and goals, 67
Smith, Cecil, *18,* 18–19, *19*
Smith, Michelle, 39
soil temperatures, 36, 109
Solar Greenhouse Book (McCullagh, ed.), 15
Spade, Katrina, 52–55
straw bales, as insulating side walls, 11–12, 70–71, 73, 98–99, 118, 126, 134
straw bedding, 35, 44, 125
structural side walls. *See* side wall structure
Sunset View Farm, *13, 48, 49,* 54–57, *56*

T

texture relative to aeration, 31
thermophilic composting process (rotting), 14, 30, 110
preconditions necessary for, 30–31, 34
Three Crows Farm, *77,* 98–101

tubing. *See* aeration tubing; PEX tubing

U

University of Massachusetts–Amherst, Graduate Thesis Project, 52–55
University of New Hampshire's Burley-Demeritt Farm, 59–60
University of Vermont (UVM), 16, 20, 37–40, 132–33
  Clean Energy Fund, 20, 38–39
  Horticulture Farm, *38–42,* 38–43, *96, 97, 132–35*
USDA Rural Development, 56

V

Vermont Alternative Manure Management Program, 47
Vermont Compost, 15, 32
Vertal, Inc.'s CityPod in-vessel compost system, 137, *137*

W

Walker, Justus, 102–4
water, in composting process, 30
  moisture level, 34, 43–44, 130
waterway pollution, 24–25
Web Energy Logger (WEL), 72, 88–89
Weiss, Zach, 104
Whole Systems Design Research Farm, 17
windrow composting method, *32,* 32–33, 59, 63–64
wood-chip-based systems, 22, 30, 34–35, 116–17
  Bioforsk Organic Food and Farming, 124–29
  Jean Pain–style systems, 13, 24, 25, 26–27, 34, 100, 116–17, 120–23
  small-scale Jean Pain system, 85
  texture relative to aeration, 31
  UMass–Amherst Graduate Thesis Project, 54
wood chippers, 26, 121

Y

Yestermorrow Design/Build School, 15, 16, 52

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